GLOBAL WARMING

HEARINGS

BEFORE THE

SUBCOMMITTEE ON
ENERGY AND POWER

OF THE

COMMITTEE ON
ENERGY AND COMMERCE
HOUSE OF REPRESENTATIVES

ONE HUNDRED FIRST CONGRESS

FIRST SESSION

FEBRUARY 21 AND MAY 4, 1989

Serial No. 101-31

Printed for the use of the Committee on Energy and Commerce

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GLOBAL WARMING

TUESDAY, FEBRUARY 21, 1989

House of Representatives,
Committee on Energy and Commerce,
Subcommittee on Energy and Power,
Washington, DC.

The subcommittee met, pursuant to notice, at 10:08 a.m., in room 2123, Rayburn House Office Building, Hon. Philip R. Sharp (chairman) presiding.

Mr. Sharp. Ladies and gentlemen, we have been waiting for our projector equipment so that two of our witnesses will be able to present slides. It is, we hear, on its way from the Senate, so we'll try to go ahead and proceed and regret the delay; typical of the efficiency around here. We can't seem to get the equipment where it's needed.

U.S. energy policy should rest on at least three main pillars: energy security, economic competitiveness, and environmental protection. Two weeks ago, this subcommittee heard, again, that our national energy security and our economic wellbeing may be at risk as we become more dependent on foreign oil. It is clear that we need to work much harder to improve the energy efficiency of our economy, as well as to increase the supply of domestic energy.

Today we ask whether our global environment is in jeopardy as well. We will hear from scientists who differ as to the magnitude of risk we face and the wisdom of changing energy policy based upon this risk. I hope they will help us sort through the conflicting accounts that have appeared in the news media. In this Congress, almost every issue that comes before our subcommittee, from energy conservation to nuclear licensing reform, will be examined with an eye on its implications for the greenhouse effect and other environmental issues.

In many cases, the goals of energy security, economic competitiveness, and protecting the environment will be compatible. For example, energy conservation promotes all three. In other cases, we will have to make tough choices. I hope the distinguished scientists before us today will help us to understand how much weight we should give to the global warming threat as we formulate our Nation's energy policy.

The Chair would now like to recognize our distinguished colleague from California, Mr. Moorhead, for an opening statement.

Mr. Moorhead. Thank you, Mr. Chairman. I welcome the start of what I believe will be an important series of hearings on energy policy implications of the global warming problem. Today's hearing, Mr. Chairman, is about what we know and don't know scientifically about the phenomenon of global warming. This is a topic which will be important to the subcommittee in reviewing future policy options and responses to the global warming problem.

I expect today's hearing will be extremely interesting since we are fortunate to have with us scientific experts with differing viewpoints on the global warming problem. While all of them appear to agree that what we are facing potentially is a very serious environmental threat, there is less consensus over other key points. These include questions over whether we have already experienced a temperature increase due to global warming and questions over how fast and how large future temperature increases will be.

All of these issues are important for our future deliberations on this problem. While I am concerned, as one Witness suggested in his written statement, that we may be harming the environment at a faster rate than we can predict the consequences, I am also concerned that we make sure that our policy responses reflect what we know and don't know about global warming.

I look forward to today's hearing and the challenge of sorting out the different viewpoints of what everyone will agree is a complex and difficult problem.

Thank you, Mr. Chairman.

Mr. SHARP. Thank you. The Chair now recognizes the distinguished colleague from Oklahoma, Mr. Synar.

Mr. SYNAR. I have no opening statement, Mr. Chairman.

Mr. SHARP. The gentleman from Texas, Mr. Fields.

Mr. FIELDS. Mr. Chairman, just very briefly, I want to congratulate you for holding this hearing today. Global warming is a very complex subject. I think this hearing is a good starting point with scientists who have differing viewpoints. I hope that we will have further hearings so that we might ultimately come to some type of consensus on what we might be able to do legislatively to deal with this problem.

Thank you very much.

Mr. SHARP. I thank the gentlemen. The gentleman from New Mexico?

Mr. RICHARDSON. Thank you, Mr. Chairman. Also, very briefly, I think it's important that you're holding these hearings. I would hope that sometime soon we also focus on the international implications of this issue. I think it's going to take a multilateral, multinational approach to deal with this problem. I think this is a positive start and, in answer to the question of the subject at hand, Global Warming: Is It Time For Action, I think the answer has to be yes.

Thank you, Mr. Chairman.

Mr. SHARP. I thank the gentleman. The gentleman from Tennessee, Mr. Cooper.

Mr. COOPER. I have no opening statement, Mr. Chairman.

Mr. SHARP. I thank the gentleman.

[The prepared statement of Mr. Leland follows:]

PREPARED STATEMENT OF HON. MICKEY LELAND

Mr. Chairman, there exists some disagreement on the cause and effects of increases in global temperatures. In fact, certain circles argue that there is no cause for concern as recent temperature increases are a natural phenomenon.

Granted, the scientific community is working with limited information and imperfect models. Notwithstanding this capacity to precisely predict the future with 100 percent accuracy, sufficient evidence indicates a trend toward warmer temperatures.

The United States needs to act. We need to address global warming and develop a national energy policy. Since Americans consume an estimated one-fourth of world energy production, we can greatly reduce atmospheric pollutants. By facilitating natural gas consumption, increasing energy efficiency, and promoting renewable energy resources, the United States can decrease pollution and demonstrate our leadership in hopes that others will follow suit.

We cannot, however, singlehandedly ameliorate global warming without international assistance. This is a global problem and one that necessitates a global commitment.

Climatologists are deliberating on the probabilities of a 2° to 4° temperature increase vis-a-vis a 5° to 10° increase and corresponding effects. I am not one to gamble with the environment—the stakes are too high.

I look forward to reviewing today's testimony and hope that our limited knowledge base does not enable us to err on the wrong side of humanity.

Mr. SHARP. The Chair would like to call forward our witnesses and we may have to take a break in a moment to have the projector set up, which we hope is about to arrive. We are delighted to have with us today Dr. Robert M. White, President of the National Academy of Engineering; Dr. Stephen Schneider, Senior Scientist with the National Center for Atmospheric Research; Dr. Pat Michaels, Associate Professor of Environmental Sciences with the University of Virginia; and, Dr. Daniel Albritton, Director of the Aeronomy Laboratory with the National Oceanic and Atmospheric Administration.

Gentlemen, we are delighted to have you with us and I think you're familiar with our processes here. We will make your written statement and other materials a part of our printed record and we will be asking you for your oral testimony momentarily. After all of you have given your testimony, then we'll ask questions of the panel.

Dr. White, I believe you do not need the projector. If I'm accurate about that, I'll let you go ahead and give your testimony and, when the projector arrives, then we'll take a quick break and set it up. So, Dr. White, we're happy to have you with us.

STATEMENTS OF ROBERT M. WHITE, PRESIDENT, NATIONAL ACADEMY OF ENGINEERING; DANIEL L. ALBRITTON, DIRECTOR, AERONOMY LABORATORY, ENVIRONMENTAL RESEARCH LABORATORIES, NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION, DEPARTMENT OF COMMERCE; STEPHEN H. SCHNEIDER, SENIOR SCIENTIST, NATIONAL CENTER FOR ATMOSPHERIC RESEARCH; AND PATRICK J. MICHAELS, ASSOCIATE PROFESSOR, DEPARTMENT OF ENVIRONMENTAL SCIENTISTS, UNIVERSITY OF VIRGINIA

Mr. WHITE. Mr. Chairman and members of the subcommittee. I am pleased to be here today to discuss the issue of climate change and, in particular, the advice which the National Academies of Sciences and Engineering and the Institute of Medicine recently presented to President Bush in our White Paper, Global Environmental Change, Recommendations for President-elect George Bush, which I submit for the record.

That paper considers many aspects of global change that I will not touch on here. I'll confine my remarks to issues dealing with the greenhouse problem. I'll talk about three questions. First, why do the academies consider it important at this time to issue such a statement, what are our principal findings and recommendations, and why do we consider it a matter for Presidential leadership?

First, why do we issue such a paper? The academies were motivated in part by the unprecedented level of domestic and international public attention and concern; more than a decade of academy studies which have laid a basis for our assessment of the problem; an acknowledgement that while scientific uncertainties exist, the weight of evidence indicates that a climate warming caused by the actions of humanity may be underway and that the consequences of such a climate change could be severe.

Our view is that when the risks of the consequences are put in the balance against the certainties and uncertainties of our knowledge, a prudent course of public action is called for. Such a course of action should address the anticipated climate changes in ways that do not preclude other options if the outcomes differ from our present projections.

Now, what are the facts? There is incontrovertible evidence of increasing atmospheric carbon dioxide concentrations, as well as increasing concentrations of other greenhouse gases. The increases of carbon dioxide are the result primarily of the increased use of fossil fuels, deforestation, and certain other human activities. The response of the atmosphere to this increase in greenhouse gases can be calculated with mathematical models.

Although the mathematical models are only approximations of the real atmosphere, and hence have many uncertainties associated with them, the evidence from these calculations by many different research groups leads to the estimate that the response is likely to be a climate warming somewhere between 1½° and 4½° centigrade when averaged over the globe at the surface of the Earth. That's for a doubling of the carbon dioxide content. We are not certain of the detailed regional and local consequences.

The climate warming, should it occur, would lead to worldwide changes in storm tracks and associated precipitation, changes in water resource availability, a sea level rise, and changes in agricultural and ecological regimes. The record of instrumental observations indicates that significant global temperature increases, as well as decreases, have occurred over the past century.

The estimates based on such observations are that over this period there has been a net warming of about one-half degree centigrade. We cannot say with certainty that this warming is due to human activities, although the increase in temperature is not inconsistent with the expectations based on general greenhouse theory. Nevertheless, these could be natural fluctuations or, in part, manifestations of unrepresentative data.

Now, what are the prudent courses of action? We can intervene through more efficient use of fossil fuels and incentives to use those that contribute least to the carbon dioxide buildup per thermal unit. For example, shifts from coal to natural gas, as well as intensified efforts to develop nonfossil energy sources, such as passively safe and publicly acceptable nuclear power, are desirable.

We can act to reduce further the use of other greenhouse gases, such as CFC's, and we can work with other nations to reduce tropical deforestation. These actions should slow the climate warming. Moreover, they are desirable for other reasons since they would also be helpful in addressing the acid rain, biodiversity, and other environmental problems. Finally, many of them make good economic sense in any case.

We can encourage adaptation policies that enhance the resilience of our social and economic systems. For example, we can seek the development of drought resistant crops. We should take into account the possibility of a climate warming in planning for water resource development. We can plan coastal development, taking into account the possible sea level rise.

The most immediate need is action to reduce the uncertainties in our knowledge through an intensified program of research on climate. The President's budget now before the Congress provides significant increases for climate research by several agencies. These increases are timely and should be supported.

Now, why does the climate change issue require greater attention at the Presidential level? The scope and consequences of a climate warming could bring about considerable disruption of many parts of the economy, as well as far-reaching ecological changes. Climate change is quintessentially an international issue. It is high on the agendas of many heads of state, including Prime Minister Thatcher of the United Kingdom, General Secretary Gorbachev of the U.S.S.R., Prime Minister Mulroney of Canada, and others.

President Bush's commitment to play a world leadership role is gratifying. Mr. Chairman, I will be pleased to answer any questions that you may have.

[Testimony resumes on p. 22.]

[The prepared statement and attachment of Mr. White follows:]

STATEMENT OF

ROBERT M. WHITE

PRESIDENT, NATIONAL ACADEMY OF ENGINEERING

Mr. Chairman and members of the Subcommittee, I am pleased to be here today to discuss the issue of climate change and, in particular, the advice that the National Academies of Sciences and Engineering and the Institute of Medicine recently presented to President Bush in our "white paper," Global Environmental Change: Recommendations for President-Elect George Bush, which I submit for the record. That paper considers many other aspects of global change that I will not touch on here.

I will briefly address three questions that are covered in detail in the report. First, why did the Academies consider it important at this time to issue such a statement? Second, what are our principal findings and recommendations? And third, why do we consider this a matter for Presidential leadership and action?

Why Did We Issue Such a Paper?

The Academies were motivated in part by

- The unprecedented level of domestic and international public attention and concern.
- More than a decade of Academy studies which have laid a basis for our assessment of the problem.
- An acknowledgment that, while scientific uncertainties exist, the weight of evidence indicates that a climate warming, caused by the actions of humanity, may be underway and that the consequences of such a climate change could be severe.

o Our view is that when the risks of the consequences are put in the balance against the certainties and uncertainties of our knowledge, a prudent course of public action is now called for. Such a course of action should address the anticipated climate changes in ways that do not preclude other options if the outcomes differ from our present projections.

What Are The Facts?

o There is incontrovertible evidence of increasing atmospheric carbon dioxide concentrations as well as increasing concentrations of other greenhouse gases.

o The increases of CO_2 are the result primarily of the increased use of fossil fuels, deforestation, and certain other human activities.

o The response of the atmosphere to this increase in greenhouse gases can be calculated with mathematical models. Although the mathematical models are only approximations of the real atmosphere, and hence have many uncertainties associated with them, the evidence from these calculations by many different research groups leads to the estimate that the response is likely to be a climatic warming of 1.5°C - 4.5°C when averaged over the globe at the surface of the earth. We are not certain of the detailed regional and local consequences.

- A climate warming would lead to worldwide changes in storm tracks and associated precipitation, changes in water resource availability, a sea level rise, and changes in agricultural and ecological regimes.
- The record of instrumental observations indicates that significant global temperature increases and decreases have occurred over the past century. The estimates based on such observations are that over this period there has been a net warming of about 0.5°C. We cannot say with certainty that this warming is due to human activities, although the increase in temperature is not inconsistent with expectations based upon general greenhouse theory. Nevertheless, these could be natural fluctuations or in part manifestations of unrepresentative data.

What Are Prudent Cources of Action?

- We can intervene through more efficient use of fossil fuels and incentives to use those that contribute least to the CO_2 buildup per thermal unit. For example, shifts from coal to natural gas, as well as intensified efforts to develop non-fossil energy sources such as passively safe and publicly acceptable nuclear power are desirable. We can act to reduce further the use of other greenhouse gases such as CFCs. And we can work with other nations to reduce tropical deforestation.

These actions should slow the climate warming. Moreover, they are desirable for other reasons since they would also be helpful in addressing the acid rain, biodiversity, and other environmental problems. Finally, they would also make economic sense.

- We can encourage adaptation policies that enhance the resilience of our social and economic systems. For example, we can seek the development of drought resistant crops. We should take into account the possibility of a climate warming in planning for water resource development. We can plan coastal development taking into account possible sea level rises.
- The most immediate need is action to reduce uncertainties in our knowledge through an intensified program of research on climate. The President's budget now before Congress provides significant increases for climate research by several agencies. These increases are timely and should be supported.

Why Does Climate Change Require Greater Attention at the Presidential Level?

- The scope and consequences of a climate warming could bring about considerable disruption of many parts of the economy as well as far-reaching ecological changes.

- Climate change is quintessentially an international issue. It is high on the agendas of many heads of state including Prime Minister Thatcher of the United Kingdom, General Secretary Gorbachev of the USSR, Prime Minister Mulroney of Canada, and others. President Bush's commitment to play a world leadership role is gratifying.

Mr. Chairman, I would be pleased to answer any questions the Committee may have.

NATIONAL ACADEMY OF SCIENCES
NATIONAL ACADEMY OF ENGINEERING
INSTITUTE OF MEDICINE
2101 Constitution Avenue, Washington, D.C. 20418

The Honorable George Bush
The President-Elect of the United States
Old Executive Office Building
Washington, D.C. 20501

Dear Mr. President-Elect:

The problem of global environmental change is now widely recognized as one of growing urgency that will require responses by your Administration. Our views on the problem and possible responses are attached.

Embedded in the diverse manifestations of this problem—global warming, ozone depletion, tropical deforestation, and acid deposition—are enormous challenges to science and engineering, to your Administration, and to the world community of nations. In many instances, data and analyses are incomplete and long-term effects remain indeterminate; in addition, there are costs to the economy embedded in any decisions made to address the problem. Yet, even with a continuing background of uncertainty, it is important to recognize that human activities are indeed changing the global environment. Prudent courses of action need to be initiated now to try to understand and predict these changes, and to move toward suitable policy responses.

As outlined in the paper that follows, we suggest three principal actions that your Administration can take against the possibility that we may be conducting an irreversible experiment with our planet.

First, the issue of global environmental change must be made more prominent in the scientific, political, and foreign policy agendas of the United States. While the issue has been given more emphasis in the past several months, the need now is for sustained and systematic attention to economic and environmental policies bearing on global change.

Second, a focal point for the deployment of national resources to address the issue needs to be established to coordinate the diverse activities related to the problem. Such activities under way within the government are often poorly coordinated and insufficiently focused on the necessary linkages between scientific understanding and policy options. Further, policies must be such that they enhance the resiliency, robustness, and range of options of the affected sectors, from energy production to agriculture to coastal development.

Third, specific actions should be taken by your Administration to address those aspects of the problem that are reasonably well understood. Thus, we suggest that you consider the following findings and responses:

- Both global warming and acid deposition are linked to heavy reliance on fossil fuels. Therefore, efforts to enhance both energy efficiency and conservation should be strengthened; means for increasing the use of the "cleanest" fossil fuels, such as natural gas, should be considered, but in the context of appraising their finite availability; and alternative non-fossil fuel energy sources, such as nuclear reactors and solar energy, need to be reappraised with more emphasis put on their use in a safe and publicly acceptable manner.
- The Montreal Protocol is an important first step toward controlling stratospheric ozone depletion. However, provisions in the Protocol should be called upon to encourage deeper reductions in emissions of ozone-destroying chemicals with a total phaseout of chlorofluorocarbon products on a reasonable time scale.
- Global warming will affect sea levels, agricultural systems, forestry, and water resources. It is not too soon to assess possible impacts and responses.
- Tropical forests are being cut down at an alarming rate. Mitigating strategies that consider the economic and other forces driving this destruction need to be implemented in collaboration with the affected nations.
- Improved predictions of the future course of the global environment require new and innovative approaches to studying the earth and its environment. A substantial investment in research and ground- and space-based monitoring activities is needed.

This is a broad agenda, and a challenging one. However, we believe that it offers a sensible approach to problems that urgently require presidential leadership and whose consequences, if realized, could be severe for all nations. Leadership by the United States could be a powerful force for uniting the nations of the world in a common endeavor vitally important to all.

Yours sincerely,

Frank Press

Frank Press
President
National Academy
of Sciences

Robert M White

Robert M. White
President
National Academy
of Engineering

Samuel O. Thier

Samuel O. Thier
President
Institute
of Medicine

GLOBAL ENVIRONMENTAL CHANGE

Human activities now match or even surpass nature as an agent of change in the global environment, as evidenced by a growing list of seemingly diverse human-induced environmental changes that have gripped public attention in recent years:

- rapid changes in the global atmosphere due to fossil fuel combustion and industrial activities predicted to change global climate;
- massive ozone depletion over the Antarctic and lesser decreases over the rest of the globe, both attributed to emissions of chlorofluorocarbons;
- large-scale destruction of tropical forests for timber, fuel, conversion to agriculture, and economic development, with consequent additions to the "greenhouse" effect and losses in plant and animal species;
- damaged lakes in New England, Canada, and Scandinavia associated with acid deposition from fossil fuel combustion.

Although the full long-term implications of these changes are as yet unclear, there is a growing perception that the future welfare of human society is to an unknown degree at risk. *Our current scientific understanding amply justifies these concerns, but also presents opportunities for effective presidential leadership and action.*

Recent events have illustrated the possible social, economic, and political implications of future global environmental change. Widespread droughts in the early 1970s set the stage for major worldwide fluctuations in grain prices. Damage to lakes and forests has created major political tensions in North America and Europe. Continued droughts in Africa have stressed the aid and relief machinery of the developed nations of the north.

The individual environmental problems that have come to public attention are intricately and inescapably interlinked, both scientifically and politically. Scientifically, their resolution requires an understanding of the physical, chemical, and biological processes that govern the earth, and of the interaction of these processes in the entire earth system. Politically, policy options to address these problems converge on the need for internationally accepted actions relating to energy, technology, land use, and economic development. Their implementation will require U.S. commitment and the development of improved mechanisms for international collaboration.

Such issues challenge political leadership. The consequences of global changes to individual political constituencies are probably several decades away, unclear in nature, but potentially serious. Remedial and adaptive actions are likely to be expensive in the short term, whereas their full benefits may be enjoyed only by future generations. Many possible courses of action in policies relating to research, energy, development, and international relations involve multiple and interlinked costs and benefits transcending both national and generational bounds. Such problems can only be assessed, and prudent long-term response policies can only be effectively developed, at the highest political levels. Global change is quintessentially an issue for leadership at the level of heads of state. The United States, in your presidential term, is well positioned to play a world leadership role.

WHAT ACTIONS ARE SUGGESTED?

It is now timely to consider prudent policy actions in three areas: *prevention, adaptation,* and *research.* These actions, which can only be set in motion by presidential leadership, are discussed below, followed by synopses of the current scientific understanding of the components of global environmental change of current concern.

Preventing Global Environmental Change

We are already irrevocably committed to major global change in the years ahead. The elevated concentrations of greenhouse gases produced to date by human activities will persist for many centuries and will slowly change the climate of the earth, regardless of our actions. The chlorofluorocarbons (CFCs) that are depleting the ozone shield have lifetimes on the order of a century. Complex tropical forest ecosystems have the ability to regenerate, but this depends on the way they are managed, and regeneration will occur slowly at best.

While global environmental change cannot be stopped, the pace of change can be slowed. Put another way, we cannot buy absolute security against environmental risk, however much we are willing to pay; but we may be able to reduce environmental damage and risk markedly by prudent policy actions outlined below.

Energy Policy

Production of energy from fossil fuels is the root of several of the agents of global environmental change, notably climatic change and acid deposition. There has been great concern, and considerable remedial action, with respect to emissions of sulfur and nitrogen compounds from fossil fuel combustion. Moreover, reductions in fossil fuel combustion address the continuing concerns for regional air quality and acid deposition, the growing concerns for global climate, and our growing dependency on foreign energy resources, i.e., petroleum.

To prepare for the possibility that the use of fossil fuels (particularly coal) may need to be reduced in the years ahead, *we should explore means for reducing energy demand without impeding economic growth, for example, by using fossil fuels with greater efficiency, as well as incentives and other means to increase use of the "cleanest" fossil fuels such as natural gas.* However, the finite availability of natural gas, a premium energy source and valuable chemical feedstock, also needs to be considered. The potential for energy efficiency gains and fuel-switching is demonstrated by the responses to the energy price shocks of the early 1970s.

A vigorous research and development program should give increased emphasis to energy sources that do not produce carbon dioxide. New technologies for publicly acceptable nuclear reactors—so-called "safe reactors"—should receive attention in an R&D program on alternative energy sources. Geothermal, wind, solar, and other renewable energy sources warrant reexamination to see if recent progress has improved their economic feasibility as possible substitutes for fossil fuels in the years ahead.

Actions by the United States alone, while setting a good example, would in themselves be only marginally effective in slowing the rate of global carbon dioxide emissions. In the decades to come, major demands for energy will come from the developing nations. These nations will have to evaluate the needs of their own economic progress together with protection of the global environment. Thus, energy policy issues are likely to be on the international political agenda.

Policies to Reduce Industrial Emissions

The Montreal Protocol to limit emissions of CFCs, signed in the fall of 1987 by 31 nations—including the United States—is an unprecedented example of international cooperation to prevent global environmental deterioration. *The provisions of the Montreal Protocol could be called on to urge deeper cuts in the production of CFCs, to accelerate the timetable for their reduction, and to urge all countries to sign and enforce the Protocol.*

Technology exists to eliminate most of the industrial emissions that cause acid deposition. The use of clean, low-sulfur coal and combustion and cleaning technologies can significantly reduce emissions in power plants. However, some emission-control techniques may be energy-intensive, thus increasing carbon dioxide emissions, and may produce solid and liquid waste products that are difficult to deal with. Thus, policies to control acid deposition involve trade-offs with measures to address other environmental problems, and often require international coordination. In any case, there are political and economic components in any decision on dealing with acid deposition; and to date such decisions have been deferred by the past two Administrations in favor of more research. We believe that the sources of acid deposition, the technology to limit emissions, and the associated costs and political risks are now sufficiently understood that further deferral in favor of more analysis is unwarranted.

Development Policy

The future course of a number of the global environmental issues discussed above will be strongly influenced by the manner in which the economies of the less developed nations evolve over the next several decades. A nation's impact on its own environment, and on that of the globe, clearly depends on its population level, standard of living, and the technologies used to support that standard. Uncontrolled growth of populations in developing countries seeking better standards of living with inefficient technologies can only lead to continued damage to the local and global environments. *Development aid policies should focus on improving the indigenous scientific and technological knowledge base and infrastructure of the developing countries as a foundation for environmentally sustainable economic development to address these nations' aspirations for a better life. Development aid decisions should include a consideration of environmental impacts.*

Adapting to Global Environmental Change

If we do no more than slow the pace of environmental change, thus gaining time to deal with its effects, we will have achieved much. Policy options to enhance our ability to cope with environmental change should therefore also have high priority. Because the detailed evolution of the expected changes cannot at present be predicted, *policies should seek to enhance the resilience, robustness, and range of options of the sectors likely to be affected.* For example, the likelihood of rising sea levels should clearly be taken explicitly into account in the planning of coastal development, construction of port facilities, location of waste disposal dumps, and so on. Possible changes in the frequency and severity of extreme events—floods, droughts, and severe storms—should also be considered. The possibilities for significant changes in regional hydrology should be considered in planning for major water-resource projects. Better understanding of the response of crops and natural vegetation to changes in climate and atmospheric composition is needed. The already impressive adaptability of agriculture may be further enhanced by investments in the development of improved crop strains, the exploitation of new crops, and technology for improving water utilization.

Options for adaptation are numerous for rich, technologically advanced nations such as ours, but fewer for poor nations. It will be in the interests of all to assist the poorer nations in reducing their vulnerability to environmental change by developing an effective range of adaptations.

Improving Understanding of Global Environmental Change

We still lack sufficient scientific understanding to predict confidently the detailed evolution of global and regional change in the environment. Obtaining this knowledge will require *strong support for research already under way, nationally and internationally, and support for new long-term programs of interdisciplinary, international research.* Monitoring global change will involve coordinated, long-term observations, both from space and on the ground. Long-term commitments must be made for resources that will make uninterrupted observations possible over the decades to come.

The acquisition of knowledge through research and monitoring is expensive, although not nearly as costly as the possible consequences of ignorance. We are already investing large resources in the study of the earth, but these efforts require augmentation and coordination.

Institutional Needs

However, current institutions and mechanisms in government and in the scientific community—both in our country and in the international community—need strengthening to assure a strong scientific program for understanding the global environment and developing timely, well-coordinated, and effective policies. *The existing mechanisms for coordination between government agencies are not adequate to address the complex scientific and policy implications of global change.*

Mechanisms exist within the federal government that could play a major role in directing the massive and diverse resources of government on this problem; notably, the interagency Committee on Earth Sciences of the Federal Coordinating Council on Science, Engineering, and Technology. However, effective direction of these governmental resources cannot be achieved solely by the normal processes of interagency coordination. Even more complex issues are posed by the need for collaboration between sovereign nations. Effective leadership and direction in this area is clearly required. The issue of global environmental change must have a prominent place on the scientific, political, and foreign policy agendas of the United States.

6

PRINCIPAL SCIENTIFIC ISSUES

The policy recommendations suggested above are shaped by our current understanding of the various aspects of global environmental change, particularly by the considerable uncertainties in our knowledge. Reducing these uncertainties would lead to more informed and effective policy decisions.

Climate Change

A central issue in global environmental change is the effect of changing atmospheric composition on global climate. The greenhouse effect—the trapping of the sun's heat near the earth's surface by small concentrations of certain gases in the atmosphere—has been well understood since the eighteenth century and is arguably the most firmly established principle in atmospheric science. These "greenhouse gases" include water vapor, carbon dioxide, methane, and the CFCs.

In the nineteenth century, marked growth in carbon dioxide concentrations began—from about 280 parts per million (ppm) in 1850 to 350 ppm today. This increase can be explained by the burning of vast quantities of fossil fuels, the massive conversion of carbon-rich forests to farmland and pasture, and the absorption of about half of the emitted carbon dioxide in the ocean. Today, fossil fuel use injects about 5 billion tons of carbon into the atmosphere each year, and deforestation adds at least 1 billion tons more. As a result, carbon dioxide concentrations are continuing to increase at about 0.4 percent per year.

Other greenhouse gases are also increasing. Methane, emitted from oil and gas wells, rice paddies, bogs, tundra, and increasing populations of creatures ranging from cows to termites, is increasing at over 1 percent per year. The principal CFCs, despite recent limitations, are still increasing at several percent per year. Other gases such as nitrous oxide and tropospheric ozone are similarly increasing. The combined effect of each year's increase in these gases is roughly equal to that of the carbon dioxide increase alone.

Estimating the influence of continuing increases in greenhouse gases on future climate requires quantitative models of the climate system, as well as predictions of how human actions will influence future emissions. Based on our current understanding of natural processes and plausible projections of population growth, technology, and economic development, it is expected that before the middle of the next century the combined effect of increases in all greenhouse gases will produce an impact on the climate roughly equivalent to a doubling of preindustrial levels of carbon dioxide alone. Numerical models of the climate system yield estimates of the effect on long-term global mean temperatures that range between 1 and 5°C (2 to 9°F). The rate of climate change implied by these estimates is as much as 100 times greater than the average rate of change since the last glacial period (when global temperatures were about 5°C cooler than today and ice sheets covered our northern tier of states), and about 10 times greater than the fastest known sustained climate change during the last 10,000 years.

Recent observations of increased temperatures are consistent with predicted changes, but we do not yet know if they actually confirm that greenhouse warming is indeed in progress. Individual disastrous climatic events, such as a dry summer or a vigorous hurricane season, cannot be attributed to greenhouse warming.

The expected rapid rate of climate change greatly complicates the task of predicting the changes most important to human society—the timing and regional distribution of changes, and the frequency and severity of extreme events. Warming should lead to worldwide changes in many features of the hydrological cycle, with consequences for soil moisture, river flow, glacier extent, and the distribution of crop zones. In addition, there are reasons to expect that warmer ocean temperatures will lead to more violent tropical storms.

The detailed consequences associated with this expected warming are still unclear. Complex changes in temperature, precipitation, soil moisture, and storm patterns could result in a web of economic impacts.

- Climatic zones and storm tracks may be expected to shift poleward. Crop zones and natural ecosystems can be expected to migrate with the changing climate, although the extent of movement is uncertain. Major shifts could clearly have far-reaching economic, social, and political consequences.
- Melting of land-borne glaciers and thermal expansion of sea water are expected to raise global sea levels significantly over the next century. Projections of the amount of rise range from tens of centimeters to as much as 3 meters, with reasonable estimates centering on a 1 meter rise. Rising sea levels will increase the already troublesome rates of coastal erosion and loss of wetlands, while increased saltwater intrusion would impair water supplies and agriculture in coastal areas.
- Warming is expected to be considerably greater in polar latitudes than in the tropics, and sea ice should diminish. A navigable Arctic Ocean would have major national security implications.
- Changes in rainfall patterns are likely, and some studies indicate greater summer dryness in midlatitude continental regions. Regional changes in water supply and quality may have significant economic and social consequences.
- Adverse climate changes may be difficult to accommodate in developing countries, where resources are not available to adapt to changing conditions. Growing pressures for migration may result.

- Implications for human health may result from changes in the range of disease vectors (e.g., insects and rodents) and in the frequency and intensity of extreme weather known to influence mortality rates.

There is a disturbing possibility for surprises as the climate system rapidly changes. The record of the past, notably as revealed by ice core records, shows that the climate system can exhibit large and rapid changes in response to slow changes in natural forcing. Today, humanity is imposing new stresses on the system, raising the question of possibly triggering climatic surprises in our own times.

Tropical Deforestation

Tropical forests are being rapidly destroyed because of the pressure of growing local populations for agricultural land and fuel wood supplies, and the strong world markets for tropical hardwoods and animal products from tropical pastures. Satellite data provide reasonably reliable estimates of the rates of deforestation; if these rates continue, the planet will be virtually denuded of tropical forests early in the next century.

This massive change in the earth's vegetation has many consequences. As noted above, the associated carbon dioxide release adds about 20 percent to the release from fossil fuel combustion. Other troublesome gases such as nitrogen oxides and ozone are also produced directly or indirectly from burning to clear land. Deforestation can also lead to long-term degradation of soil fertility, and is intricately linked to significant changes in regional hydrology and climate. Perhaps the most serious long-term impact of tropical deforestation is the loss of plant and animal species. This loss of genetic resources may rob us of valuable options for future resources for food, industry, and health. Many of these changes are irreversible, and the full range of their long-term consequences is poorly understood.

Stratospheric Ozone Depletion

Ozone is naturally produced in the stratosphere by the interaction of sunlight with oxygen. Although present only in small concentrations, it blocks out highly damaging solar ultraviolet radiation, and is thus essential to life.

Observed ozone concentrations (a few parts per million) are maintained by a balance between ozone production and natural ozone-destroying chain reactions involving extremely small concentrations of nitrogen, hydrogen, and chlorine compounds. The CFCs, synthetic chemicals widely used in industry and consumer products, are known to enter the stratosphere, where they provide a new primary source of chlorine. This relationship between surface release of CFCs and global stratospheric ozone loss was identified in 1974.

The discovery of the Antarctic ozone "hole"—the abnormal depletion of ozone over the entire Antarctic continent in the early Southern Hemisphere spring—was brought to world attention in 1985. In the last 2 years, ground-based and high-altitude aircraft experiments have indicated that the ozone depletion is related to CFC concentrations, and laboratory experiments are clarifying our understanding of the mechanisms involved.

Small worldwide decreases in total ozone have recently been detected through careful analysis of surface-based and satellite observations. These changes amount to a few percent, and vary markedly by latitude and season. Such systematic long-term declines in ozone are accompanied by large natural seasonal and interannual variability, which can mask underlying trends.

The best understood implications of stratospheric ozone depletion lie in human health. Changes in total ozone of 5 percent in the middle latitudes would raise ultraviolet radiation levels at the surface enough to increase skin cancer incidence by more than 10 percent. Immunological changes also may result from ultraviolet exposure. Effects on plants and animals are poorly understood, although there are grounds for concern. Effects on food chaina in the world ocean, with ultimate effects on fish harvests, as well as effects on agricultural crops and natural systems are also likely but have not yet been assessed.

Acid Deposition

Fossil fuel combustion in power plants and in autos produces oxides of sulfur and nitrogen, which are converted to acids in the atmosphere. These compounds are transported in the atmosphere over long distances and are responsible for reduced visibility and increased deposition of acids on the ground across large regions.

Increased deposition of acids in forested areas of the northeastern United States, Canada, and northern Europe that have low-alkalinity waters and thin, acid soils has resulted in the acidification of surface waters, sometimes to the extent that they no longer can support normal fish populations. The linkage between fossil fuel combustion and acidification has been demonstrated.

Acid deposition may be considered as one aspect of a changing "global chemical climate," with many varied and interlinked effects. For example, changes in the "chemical climate" have accelerated the corrosion and erosion of buildings and historic monuments. A serious concern is the possibility that changes in the deposition of nitrogen and sulfur compounds have significant effects on forest productivity. However, the full impact of acid deposition and other pollutants on forest productivity and its relationship to the decline of some North American, Canadian, and European forest species is not fully understood, and the mechanisms of forest damage are not clearly established.

Another aspect of the changing chemical climate is increased concentrations of ozone at ground level, resulting from reactions between nitrogen oxides, hydrocarbons, and sunlight. Ground-level ozone increase has also been implicated in human health problems and significant crop losses. Although the degree of increase is uncertain, ambient levels of ground-level ozone in the summertime have been associated in experimental trials with a loss of growth and altered physiological function of forest trees.

Finally, ozone in the lower atmosphere acts as a greenhouse gas, and the effects of a changing chemical climate on biological processes undoubtedly influence the fluxes of other greenhouse gases as well.

As a final comment, we believe that global environmental change may well be the most pressing international issue of the next century. The United States is well positioned to play a leadership role in coping with and gaining an international consensus on this difficult issue. Indeed, the United States in the past has had a major role in examining the problem—whether through the carbon dioxide measurements done on Mauna Loa, the analysis and development of the experimental evidence for the relationship of the Antartic ozone depletion and CFCs, the substantial contributions of American scientists to creating mathematical models of climate, or United States leadership on the Montreal Protocol.

Mr. **Sharp**. Thank you very much, Dr. White. Let me ask. I believe Dr. Schneider and you need the projector. Am I correct? And, Dr. Michaels, you had planned on the projector. Why don't I ask Dr. Albritton, under those circumstances, if you do not need the projector, to go ahead and then we'll return to that. So, Dr. Albritton, we'll be glad to hear from you at this point.

STATEMENT OF DANIEL L. ALBRITTON

Mr. **Albritton**. Thank you, Mr. Chairman, members of the subcommittee. I certainly appreciate the opportunity to appear before you today to discuss global warming. As you requested, in my verbal remarks I will concentrate on three topics. First, a very brief summary of the uncertainties associated with global warming; second and with most emphasis, the current activities in the international scientific community to provide an assessment of that state of knowledge; and then finally, perhaps comment on some of the highest priority research items that are needed to reduce those uncertainties.

To be sure, as has already been cited, the past and present research have provided us with a substantial understanding of several aspects of the greenhouse effect. However, while some things are known with high certainty, others are very poorly understood. So the spectrum that I'd like to outline for you extends from the set of knowns, that is high degree of scientific consensus and certainty, to basically unknowns for which science can make no comment at present.

For example, one item over which there is no longer scientific debate, as has just been alluded to, is that carbon dioxide is increasing in the atmosphere, clearly due to the hand of man and, based on current estimates, it is virtually certain that it will double compared to industrial times some time in the next century.

Second, it's also a very well known that there are other greenhouse gases besides carbon dioxide. CFC's, nitrous oxide, and others operate physically and in exactly the same fashion and it's well known that they add to the CO_2 effect, perhaps as much as a factor of two. Third, scientific confidence is very high in the basic understanding of the basic physics of how such gases trap heat in the atmosphere.

However, in terms of how the planet will respond to this additional trapped heat, most scientists, but not all, currently believe that the eventual response to the buildup of these gases is a global warming somewhere on the range that has been cited of one to a few degrees Celsius. Third, there is a wide spectrum of opinion at present as to whether a greenhouse signal has actually been seen in the temperature record. This is a point that has had considerable scientific debate and we'll hear more about it at this hearing.

What most scientists believe, in my impression, is that it is a bit early to call in terms of identifying cause and effect for observed temperature trends and the implied greenhouse effect. Last, approaching now the level of where science cannot yet make a definitive statement, current models of climate do not have the ability to predict climate on a particular season for a particular year and a particular place on Earth.

The relevance of that statement of uncertainty is that it implies that last year's tragic midwestern drought cannot be, by cause and effect, attributed yet, via global models, to the greenhouse effect, nor can such models predict what the climate is going to be in the next few years. However, perhaps the lesson to learn from the environmental problems of last year is not what is their cause, but a demonstration of how an advanced society like ours still has remarkable sensitivity to the changes in nature.

You'll hear these statements again in this hearing. The scientific uncertainty ranges from a known of increasing carbon dioxide to the inability to predict the climate of one region or one place or 1 year. The reason I repeat them here is that I think it's important to hear the different perspectives of how those are stated, but probably more important, the reason I state them is that you will hear perhaps three such statements out of the proceedings this morning.

I want to use them to underscore that there is work in progress that will be of even more use to you, that is an international assessment by the world's best scientists, sponsored by the leading scientific organizations, the World Meterological Organization [WMO] and the United Nations Environmental Program, an international scientific assessment that will come out with a single statement on the status of understanding the climate change.

I'd like to take most of my time this morning to outline to you the main features of that. First, there will be three such assessments. One will try to summarize the understanding of the science; the second, the socioeconomic impacts of climate change; and third, what kind of policy options exist based on the studies of the science and the impacts.

The United Kingdom is chairing the one on science, but there are several nations involved, of course including the United States. The U.S.S.R. is chairing the one on socioeconomic impacts and the U.S.A. the one on policy impacts. Let me describe to you very briefly what the United States has done in its role on the science assessment. Beginning last June, the Committee on Earth Sciences charged myself and my NASA colleague, Bob Watson, to begin to put together a draft plan of how the United States would participate in the science assessment.

The highlights of those steps were as follows. Dr. Watson and I reported the initial outline back to the CES in July of last year. Simultaneously, we called together a group, an ad hoc group of U.S. experts whose expertise went far broader than just the two of us to look over what we had done. We also outlined what we had done to the Domestic Policy Council Climate Working Group to assure them that policy questions would be embraced by such scientific studies.

Last, we described a plan to the Climate Research Council of the National Academy of Sciences and, with such excellent input, we felt very comfortable, Dr. Watson and I, in meeting informally with the United Kingdom Chairman last December of the Science Working Group to begin to hammer out the tasks that the International Science Working Group would have.

This group met in Oxford, in England, in January, last month, and a summary report of that meeting is available and let me just tell you what the highlights were. First, the work of the Science

Assessment Group will have as a product a peer reviewed scientific assessment of the current knowns and unknowns associated with climate change. It will basically be a scientific document that will, of course, be accompanied by a summary directed to decisionmakers in the general public as well as industry.

The scope of the document will be full and that is it will extend from those things that cause climate change, be they natural or be they manmade, to the processes by which the planet responds to the biological and physical responses, like sea level change, temperature change, ecosystem migration, that would accompany such changes. A special emphasis throughout the document will be trying to identify very clearly the gaps in the knowledge, that is to better aid research planning, and a better quantification of the uncertainties, to try to go beyond words like "very likely" or "quite probably."

The timetable for finishing this is very brisk. The lead authors in the science document will meet next month at the NOAA, Geophysical Fluid Dynamics Lab [GFDL] in Princeton, NJ. The plan is to have a rough draft of this assessment finished by the end of 1990 and to be able to report to the countries of the world through the second world climate conference in the United Nations General Assembly by late 1990 what the best status is of the scientific understanding.

Now, of what value will such an assessment be to those like yourselves who have to wrestle with the assessment of taking policy options based on scientific input? I think the answer to that value of the assessment is going to be considerable, but let me outline some of the reasons that I say that. First, it will be a strong single statement of the global scientific community. In contrast, although they are useful, to the separate and sporadic statements that individual scientists have made at different times and different places.

Second, it will be an international statement and that is it is one atmosphere that we share on this planet, it is one climate system, and as we grapple with the policy, it's clear that a level scientific playing field will aid that process of policy discussions. Third, it will emphasize both natural climate changes and manmade climate changes. The utility of looking at both is that it puts the perspective on statements made about the manmade changes.

That is it can compare what we may or may not be doing to what nature does on its own in terms of change in the climate system. Finally, I think the explicit focus on risk and uncertainties—I'm sorry. The explicit focus on gaps in knowledge and in uncertainties of understanding will aid risk analysis by decisionmakers like yourselves.

I have outlined in my written testimony some of the major research gaps that are already on the table that obviously will be debated by this scientific body and I will refer you to that for itemized problems of scientific need. Let me close by pointing out that clearly all historical data show us the climate system has changed substantially and severely in the past, long before we possessed the dubious capability to participate in that change.

There is certainly every reason to believe, based on our understanding of how the planet works, that such natural change is going to continue in the future. There is now, however, the likely prospect that we will contribute to that change and I think there are two implications to the fact that climate will change and that we may participate in that change.

Those two points have separate, distinct, and different policy questions. First, regarding natural climate variations, we know that they are of such magnitudes that science should be able to do a better job in explaining when they're going to come and what will be their nature. Basically, science should help you with answering the question, how can we accommodate large natural variations in the climate.

Second, regarding human-induced change, the question is very distinctly different. It's not one of accommodation. It's one of asking ourselves do we believe it, do we believe our understanding sufficiently well that we need to mend our ways. Obviously, policymakers will be addressing both of those questions. Scientists must also assist with both answers. The improved answers from a science perspective require a fundamental understanding of how the ocean and atmosphere are coupled, how they work, and how they respond to forcings like solar changes, as well as greenhouse gas changes.

That's a daunting task for science. Nevertheless, I think it's clear to everyone that the fundamental understanding of natural processes as they relate to the wellbeing of mankind are almost always cost-effective, both in terms of money and, at the time, of the best people that will be putting their mental energies to it. For example, the comparison of the cost of a single Salk-Sabin vaccine to the human and economic cost of an iron lung teaches us what can truly be achieved when the cause of the thing is understood.

Regarding our environment and what it means to us, it is the price of ignorance in these matters that we really can't afford.

Mr. Chairman, this concludes my remarks. If the goal for gravity has obscured clarity anywhere, I would certainly be pleased to expand on this with questions.

[Testimony resumes on p. 44.]

[The prepared statement and attachments of Mr. Albritton follow:]

TESTIMONY OF
DR. DANIEL L. ALBRITTON
DIRECTOR, AERONOMY LABORATORY
ENVIRONMENTAL RESEARCH LABORATORIES
NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION
U.S. DEPARTMENT OF COMMERCE

BEFORE THE

SUBCOMMITTEE ON ENERGY AND POWER
COMMITTEE ON ENERGY AND COMMERCE
U.S. HOUSE OF REPRESENTATIVES

FEBRUARY 21, 1989

Mr. Chairman and Members of the Subcommittee:

My name is Dan Albritton. I am Director of NOAA's Aeronomy Laboratory in Boulder, Colorado, which studies the chemistry and dynamics of the Earth's atmosphere. I appreciate this opportunity to appear before your Subcommittee to discuss global warming.

As you requested, I will focus this summary on three topics: (1) the uncertainties in our scientific understanding of global warming, (2) the current efforts of the international scientific community to assess that state of knowledge, and (3) the highest-priority research that is needed in order to reduce those uncertainties.

I. SCIENTIFIC UNCERTAINTIES

Past and present research have provided an understanding of several aspects of the greenhouse effect, the warming of the Earth's atmosphere through the absorption of longwave radiation by certain gases like carbon dioxide. Some things are known with high certainty; others remain very poorly understood. This testimony will summarize this spectrum of knowledge and uncertainty, ranging from unequivocal increases in the atmospheric abundance of carbon dioxide (a "known") to the inability to predict the climatic consequences for a specific region and year (an "unknown"). The focus in this summary is on the most policy-relevant aspects, namely, those points relating to the following questions:

- What can cause climate change, particularly human activities that may influence change?

- What are the predicted changes associated with human influences, and how do they compare with natural variability?
- Have we seen any human-induced changes yet?
- What is the degree of confidence in current predictions?

The following summary is my personal interpretation of the current spectrum of viewpoints in the scientific community regarding the state of the science of the greenhouse effect.

A. Human-Influenced Climate Forcings

- Given current trends in emissions, a doubling of carbon dioxide in the next century, compared to pre-industrial levels, is virtually certain.

  The atmospheric abundance of carbon dioxide is increasing, in large part due to the combustion of fossil fuels by humans. All scientists are convinced of this. The future rate of increase will depend strongly on (1) technical developments, economic factors, and policy decisions which cannot be predicted in advance, and (2) the net uptake of carbon dioxide by vegetation and the oceans, the effect of which is still somewhat uncertain. Nevertheless, essentially all scientists agree that a doubling of carbon dioxide abundances will occur within the next century.

- The existence of other greenhouse gases is well known.

  Methane, chlorofluorocarbons (CFC's), ozone in the lower atmosphere, and nitrous oxide are also greenhouse gases. Their abundances are also increasing in the atmosphere. The reasons for these increases are only partially clear. The CFC's are industrially produced; however, the sources of the other gases are not as clear because the biological mechanisms for their emission characteristics are particularly ill-defined at present. While the future atmospheric abundances of these gases cannot be reliably predicted yet, it is clear that they will add to the greenhouse effect produced by carbon dioxide.

- Confidence is high in the understanding of the basic radiation physics of trace gases.

  The above mentioned gases act to reduce the loss of outgoing thermal radiation to space, thereby increasing the radiation back toward the surface of the planet. Thus, scientists are in solid agreement that the greenhouse gases increase the "thermal forcing" of the climate system.

B. Climate System Responses

- Most (but not all) climate scientists currently believe that the eventual response of the climate system to greenhouse forcing is likely to be, on the average, a global warming. While it is clear that current science can accurately calculate the thermal forcing of the atmosphere due to increases in the greenhouse gases, it is also clear that estimating the subsequent response of the climate system to that forcing is a much more difficult task. Several of the key processes which govern that response are quite complex, for example, the occurrence of clouds and their ability to reflect radiation. Many of these processes are so-called "feedbacks." An example is ice and snow which melt during warmer periods, exposing darker surfaces that absorb more radiation and add to the warming; hence, the warming is amplified. Other processes could involve negative feedbacks which would dampen the warming. It is the net effect of the interactions among all these processes, including positive and negative feedbacks, that determines the new equilibrium climate state that the planet will reach after an increase in radiative forcing by the greenhouse gases.

  Scientists have simulated this complex system with computer models and have used these models to estimate the consequences of a doubling of carbon dioxide. Based on those simulations, many scientists believe that an eventual global average warming in the range of 1-5 degrees Celsius is a reasonable estimate. Based on disagreements among models and different approaches to simulating nature, some scientists, however, caution that we have not identified and/or characterized all of the key processes; hence, the above uncertainty range may be optimistically large. If, however, a warming in the range of 1-5 degrees Celsius were to occur, it would be comparable to, or substantially larger than, the known temperature changes that have happened naturally in the past.

- There is a wide spectrum of opinion (and no consensus) on whether a greenhouse "signal" has already been seen.

  Current models predict that, due to the greenhouse gases already in the atmosphere, the global average surface warming should be in the range of 0.5 to 1 degree Celsius. Has that warming been seen in the temperature record? The answer is not clear. While the surface temperature record shows that there has been an increase of that magnitude over the past several decades, the pattern of that increase - one relatively rapid increase in the 1920's and another in the 1980's - does not match that predicted from models of the greenhouse effect, namely, a gradual increase in temperature. This suggests that our models may be incomplete, or that there are other, presumably natural, processes at work that can influence temperature changes of a fraction of a degree Celsius. As a consequence, scientists are searching for a "signal" whose magnitude is likely to be comparable to the natural variations of the climate system, which is a challenging task indeed! Furthermore, the reliability of some of the temperature records, both global and regional, have been questioned, adding another complication. On a regional scale, for example, a recent analysis of about 100 years of temperature and precipitation records for about 6000 U.S. weather stations shows no statistically significant evidence of an overall increase in annual temperature or change in annual precipitation for the contiguous United States between 1895 and 1987 (Geophysical Research Letters, Vol. 16, No. 1, pages 49-52, January, 1989). Thus, for several reasons, the current differences of opinion among scientists as to whether the greenhouse warming has actually begun are substantial.

- Current models do not have the ability to predict the climate of a particular region or the climate of a given year. Other socially relevant climate variables, such as rainfall, are also difficult to estimate with climate models.

Those who construct climate models clearly state that models are not yet sufficiently realistic representations of the global system to yield reliable estimates of climate features on regional scales. Similarly, they cannot estimate the climate of a particular year. This means that the models cannot say whether the U.S. midwestern drought of 1988 was due to the greenhouse effect, nor can they predict the climate features of the next few years. However, many scientists do believe that the models can (and do) suggest that, because of the greenhouse effect, regional changes in climatic patterns, like the U.S. midwestern drought, would become more likely in coming decades.

II. STATE-OF-KNOWLEDGE ASSESSMENT

I would now like to summarize an assessment process that will undoubtedly be of great use to national and international efforts to evaluate and respond to potential changes in global climate. Namely, the World Meteorological Organization (WMO) and the United Nations Environment Programme (UNEP) are sponsoring the Intergovernmental Panel on Climate Change (IPCC) to obtain an international, state-of-knowledge review of climate change.

A. Timetable and Content

The main features of this Scientific Assessment of Climatic Change are as follows:

- There are three companion WMO/UNEP assessments taking place: (1) science, (2) socio-economic impacts, and (3) policy options.

- They will be prepared internationally, with the following leaders: science - U.K.; socio-economic impacts - U.S.S.R; and policy options - U.S.A.

- The highlights of the process and schedule that the U.S. is following in their participation on the Science Working Group are the following:

  - The Committee on Earth Sciences (CES) charged Messrs. Albritton (NOAA) and Watson (NASA) to draft a plan for a scientific assessment which would provide the basis for U.S. involvement. (June, 1988)

  - Draft plan described to:
    - CES (July, 1988)
    - Ad Hoc Group of U.S. Scientific Experts (July, 1988)
    - Domestic Policy Council Working Group (September, 1988)
    - National Academy of Sciences (October, 1988)

  - Watson and Albritton, representing CES, met informally in London with the U.K. Chairman to discuss plans for the Science Assessment. (December, 1988)

  - The U.S. position and plans were completed. Albritton and Watson were named as (i) representatives of the interagency steering committee for IPCC and as (ii) the U.S. delegates on the IPCC Science Working Group. (January, 1989)

  - The Science Working Group met in Oxford, U.K. and established the plans for the Scientific Assessment. A summary report is available. (January, 1989)

- The main features of the Scientific Assessment of Climatic Change are the following:

  - It will be a peer-reviewed scientific document done by the best scientists available and submitted to the IPCC. It will be accompanied by a summary directed to government officials and suitable for IPCC release, to the private sector, and the public.

  - Its scope will be the full climate change phenomenon, namely: climate forcing agents, past climate record, processes involved in climate change, climate model formulation, tests of climate models, predictions of past and future climate, and physical and biological responses to climate change.

- A special emphasis throughout will be an identification of gaps and knowledge and a better quantification of uncertainties.

o The timetable is brisk: lead authors will meet in early March, 1989; a draft will be available for review in December, 1989; lead authors and Science Working Group will examine the revised draft in April, 1990; and the Assessment will be provided to the IPCC in September, 1990 and to the Second World Climate Conference and the United Nations General Assembly in late 1990.

B. Relation to Policy

Of what value will this Assessment be to decision-makers? The answer is "considerable," but it may be useful to elaborate here on the fundamental reasons why this is true:

o It will be a strong single concise statement from the scientific community.

In the Assessment, major representatives of the scientific community will speak at one time regarding the knowns and unknowns of climate change, including global warming. Dissenting viewpoints and their biases will be clearly stated. This can be a common reference point for decision-makers, in contrast to sporadic and separate statements reflecting the opinions of individuals.

o It will be an international scientific statement.

All nations would have a common basis of scientific input for their decision-making, as opposed to several national statements.

o The scientific scope will be comprehensive.

With the Assessment, decision-makers will have available a single, homogeneous summary of the current scientific understanding of the whole climate change phenomenon, ranging from the causes of change to the physical and biological responses to that change. This is likely to be more useful than separate reviews of components of the phenomenon done at different times and perhaps for different purposes.

o Both natural and human-induced climate change will be considered.

In contrast to considering only the potential perturbation of climate by human activities, the Assessment will place that predicted change in the context of the observed and predicted changes that are a natural part of the climate system. The comparison of the two will afford an immediate and straightforward insight into the significance of any predicted human-induced perturbations.

- The focus on identifying gaps and knowledge quantifying uncertainties will aid risk analysis.

  The difference between (a) "The predicted range of possibilities is from X to Z." and (b) "The prediction is Y." is, with regard to decision-making, a highly relevant difference, since the first explicitly reflects the existence of uncertainties in the prediction.

III. RESEARCH NEEDS

While the Assessment will usefully summarize the current state of understanding, it is clear that key issues related to global warming need further elucidation. Therefore, it will prove to be crucially important over the coming years to continue to improve, test, and assess our understanding of the phenomenon, as embodied in numerical, climate-system models.

These models are, of course, only as good as the accuracy and completeness with which their components represent the relevant processes of the "real" world. Some of the shortcomings of our understanding of these processes are clear now, and hence, define some of the priority tasks that need research emphasis. Other required tasks are associated with establishing a better observational system that could not only provide additional input to the models, but also could serve as a means of detecting whether greenhouse warming is taking place. Resolving these shortcomings will require collaborative research among several disciplines, including atmospheric and biological sciences.

Some of the highest-priority needs are the following:

- Better characterization of the cloud feedback mechanisms, such as observations and theories that can relate the radiative effects of cloud-scale processes to planetary-scale processes.

- Identification of other significant feedback processes, such as biogenic emissions/cloud-formation interactions.

- Better experimental and theoretical understanding of the biological, chemical, and physical processes that control the emissions and uptake of the radiatively important trace gases other than carbon dioxide.

- Defining the trends of likely additional greenhouse molecules, such as lower-atmospheric ozone and stratospheric water vapor.
- Characterizing the trends and spatial variations of climate-sensitive properties, such as temperature and ozone, in the middle-to-upper stratosphere.
- Better global coverage of the observations of key response variables, such as surface temperature and albedo globally at oceanic locations and a better monitoring record of sea level.
- Establishing more accurate decadal trends in the radiative forcings, such as cloud cover, in order to develop and test improved models of key feedback systems.
- Improving the understanding (that is, the observations, process studies, and modeling) of major subcomponents of the climate system, such as the coupled ocean-atmosphere of the equatorial South Pacific, since these submodels are part of the basis of eventual global coupled models.
- Better characterization of the processes that determine the thermal inertia of the oceans, such as large-scale vertical motions.
- Improving the quality of, and learning to interpret better, the long-term record of past climate change in order to develop and test our century-scale models, as a means of validating models within the range of experience before using them under new conditions.

EPILOGUE

Global climate has often changed substantially and severely in the past. There is every reason to believe that such natural change will continue in the future. There is now the likely prospect that human activities will add to climate change in the future. There are two implications for us to consider. They both have separate, different, and equally important associated policy questions.

(1) Natural Variation: How do we accommodate it?

(2) Human-Induced Variation: Do we need to mend our ways? Policymakers will be addressing both questions. Scientists must assist with both answers. Improved answers require a better understanding of the fundamental processes of the ocean/atmosphere climate system, which is a challenging task.

Nevertheless, the fundamental understanding of natural processes that relate to the well-being of mankind are almost always cost-effective. For example, comparison of the cost of a Salk/Sabin vaccine for polio to the economic and human costs of an iron lung teaches us what can be achieved when the cause of a thing is truly understood. Regarding our environment and what it means to us all, it is the price of ignorance that we cannot afford.

Mr. Chairman, this concludes my prepared remarks. I would be pleased to answer any questions that you or the members of the Subcommittee may have.

STATEMENT FOR THE RECORD
THOMAS R. KARL
RESEARCH METEOROLOGIST
NATIONAL ENVIRONMENTAL SATELLITE, DATA, AND INFORMATION SERVICE
NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION
U.S. DEPARTMENT OF COMMERCE

BEFORE THE

SUBCOMMITTEE ON ENERGY AND POWER
COMMITTEE ON ENERGY AND COMMERCE

U.S. HOUSE OF REPRESENTATIVES

February 21, 1989

Mr. Chairman and Members of the Subcommittee:

I want to thank the Subcommittee for the opportunity to submit the analyses my colleagues and I have recently completed that relate to the issue of greenhouse warming. Attached is a one-page summary of our major findings.

This testimony describes temperature changes seen over the United States during the past century. A short introduction regarding the relationship of our work to the greenhouse issue is appropriate.

Increases in scientific understanding must follow three basic steps. First, a hypothesis must be developed based on our understanding of the physical world. In context with today's discussion, this may be stated as: increases in anthropogenic greenhouse gases like carbon dioxide will lead to global warming. Second, the hypothesis is used to make some predictions about the physical world. In this case, predictions are being made with three-dimensional mathematical climate models. These predictions include a forecast of a global warming between 1.5°C (2.7°F) to 4.5°C (8.1°F) assuming a doubling of carbon dioxide concentrations, or the equivalent in radiatively-active greenhouse gases.

Despite the success of these climate models in reproducing important features of the annual cycle and other aspects of the climate, there remain too many deficiencies in scientific understanding of various climate-system components to make a realistic climate model. For this reason, we must take the third step: the comparison of model predictions with measurements made from the physical world. If our measurements are in agreement with our predictions, we can have a certain measure of confidence about our predictions. If they do not agree, we must either modify or reject our hypothesis.

The massive volume of weather observations which form high-quality climate data bases archived by the National Oceanic and Atmospheric Administration has allowed us to actively pursue the third step. Specifically, we have attempted to focus on some of the details of climate change over the past 100 years. At face value this may seem like a relatively simple task, but it turns out to be extremely complex. The weather observing networks across the globe were designed to assess day-to-day weather changes, not to detect climate change -- a change that may be evidenced by temperature differences of only a few tenths of a degree Celsius.

Inconsistencies in these networks have produced a number of biases in the climate record. These biases must be removed before we can have confidence in any trend that surfaces. Some examples of the more serious biases that have been introduced into land-based weather records include:

- Changes in observing schedules which have been shown to produce biases in the mean temperature of up to 1.0°C (1.8°F)

- Rapid increases in urbanization which can lead to biases of the mean temperature of over 1.0°C (1.8°F)

- Changes in station location, instruments, instrument shelters, and height of the instruments above ground have lead to biases of 1.0°C (1.8°F) or more.

Temperature observations from the oceans also contain a number of biases. Sea surface temperatures readings are sensitive to the types of containers used. Changes in containers, for example, wooden, metal, or canvas buckets, and intake tubes for engine cooling, can lead to biases over 0.5°C (0.9°F). Marine air temperatures are also subject to biases introduced by changes in the mass of ocean ships and their deck height above sea level. Adjustments in the marine data have been applied to reconstruct global temperatures, but a number of assumptions are required to properly use these corrections. Because of poor documentation regarding the types of measurements, particularly prior to World War II, there is skepticism concerning these assumptions.

Because of the many potential biases in various data, we have tried to make use of one of the most comprehensive observing networks on earth, namely, the weather observations that have been collected across North America, and in particular the observations of surface temperature over the United States. We have had access to comprehensive weather station histories which include information regarding changes in instrumentation, observing schedules, population, station locations, and instrument height above ground. We have used this information to adjust for such changes made since the turn of the century. We have had access to over 1200 stations which are in computer-compatible format. This network has been called the Historical Climate Network (HCN). It is a dense data set that, by comparison, consists of about half the number of stations used to study changes of land surface temperature across the entire globe. This still represents a small fraction of total surface area of the earth and is not an adequate sample for the globe. The added density and access to comprehensive station history information allows for a more thorough assessment of these variables as they effect the climate record than other, lower-density global data sets.

Additionally, the HCN allows us to investigate changes in the average maximum and minimum temperatures, and their relationship to changes in cloudiness and sunshine as measured by sunshine recorders and human observers. This additional cloud vs. temperature analysis is important to understanding the climate system. By far, atmospheric water vapor is the most important greenhouse gas on the planet, yet the role of clouds is among the most significant uncertainties in climate modelling. A small increase in global cloudiness could ameliorate most or all of the greenhouse effect.

Figure 1 shows our analysis of the changes in temperature across the contiguous United States in four panels. The panels show changes in mean maximum and minimum temperatures, the overall mean temperature, and the range between the maximum and minimum.

The overall mean temperature in the United States from 1901 through 1988 has increased 0.2° Celsius (0.4° F.). The rate of increase, however, has not been uniform over time. In fact, the mean temperature of the contiguous United States is better described by a significant warming of over 0.6°C (1.1F) from the turn of the century to the mid-1930s, followed by a cooling trend of about half this amount since the mid-1930s. Other scientists, including Dr. Henry Diaz of NOAA and Dr. Pat Michaels of the University of Virginia, have found similar results for the North American continent using Canadian as well as U.S. data. The last few years of the temperature record have been warm, but this warmth has not been of sufficient duration to establish a significant trend, nor reverse the observed cooling trend since the 1930s.

Mean temperature trends only describe part of the climate picture, however. The trends of the maximum and minimum temperature are of particular interest in evaluating greenhouse effect. Since the 1950s, the averaged minimum temperature has increased to one of the highest levels of the 20th Century. The nationally-averaged maximum temperature, however, has not increased. In fact, it has decreased since the 1930s.

Recent studies indicate that the increase of the daily low temperatures and reduced daily high temperatures are related to a net increase in cloud cover over the United States. Trends toward more low clouds, especially during summer and fall, have been observed since the 1950s. Although we do not know for certain, it is possible that the increase of clouds could be related to increases in greenhouse gases. Whatever the cause, the relationship between the increase in cloud cover and surface temperature changes highlights an important climate-system interaction that we need to better understand. Drs. Ramanathan and Cess of the University of Chicago and the University of New York recently used NOAA and NASA satellite observations to highlight this interaction.

Our results emphasize the importance of differentiating between changes of daytime (maximum) and nighttime (minimum) temperatures. This distinction deserves more attention in ongoing climate modelling and assessments.

Changes of the mean temperature over the United States calculated from the HCN were compared to the changes of temperature calculated over this area in two commonly cited global temperature data sets, one derived by Dr. James Hansen and colleges at NASA, and the other by Dr. Philip Jones of the University of East Anglia. The latter data set has been referred to as both the Wigley data set and the DOE global data set.

Figure 2 depicts temperature changes in the United States from 1900 to the 1984 period for each of the three data sets. The trends are in general quantitative agreement. They all depict a strong warming from 1900 to the 1930s, and a cooling since that time. However, the quantitative differences in the trends are not trivial.

Figure 3 depicts these differences over time. If there were no biases present in the data sets, the differences over time should be random. However, the Hansen data set warms by nearly 0.4°C (0.7°F) per century relative to the HCN data. The Jones data set warms by 0.2°C (0.4°F) per century relative to the HCN data set.

The differences can be explained by the increased urbanization in the global data sets compared to the HCN. The magnitude of the differences can be predicted using a set of relationships between population and the magnitude of the urban heat island bias for the United States. These relationships indicate that the urban growth around the stations used by Jones and Hansen has been sufficient to cause warm biases of this magnitude.

We concluded that the bias in these two global data sets over the United States amounts to 0.4°C (0.7oF) per century in the Hansen data and 0.2°C (0.4°F) in the Jones data. Since we found an overall warming of only 0.2°C (0.4°F) since the turn of the century, we consider these biases significantly large.

We would like to know whether a similar bias exists in other parts of the globe. Due to a lack of computer-compatible urban and rural weather station information in many parts of the world, we cannot accurately predict the magnitude of the bias. We know from case studies that the magnitude of the urban heat-island effect is dependent on the climate of the region in which an urban area is located, as well as its surface and geometric characteristics. The amount of anthropogenic heat released from the city, related in part to population, is also important.

My speculation is that the urban bias is likely to reduce the overall global warming observed since the end of the nineteenth century to a value less than 0.5°C (0.9°F), but more than 0.3°C (0.5°F). To be more specific requires additional computer-compatible urban and rural station surface temperature observations from other parts of the globe, along with population statistics.

We compared our North American analyses to global temperature trends. Similar to North American trends, the warming over the globe since the late nineteenth century has been discontinuous, a result not predicted by greenhouse forcing. Statistical analysis of the data, ignoring the urban bias, indicates that the thermometric record is better described by a series of trends that appear to be more step-like than gradual. The globe appears to have warmed 0.5°C (0.9°F) from 1880 to 1938, cooled 0.2°C (0.4°F) from 1941 to 1972, and then warmed 0.3°C (0.5°F) since 1972.

We do not understand why the global climate cooled from 1941 to 1972 when greenhouse gases were increasing. Anthropogenic greenhouse gases have increased about 40 percent over the past 100 years, according to Dr. Ramanathan and Dr. Wigley of the University of East Anglia. Using this figure, and accounting for uptake of heat by the oceans, global warming over the past 100 years should be in the range of 0.5 to 1.1°C (0.9 to 2.0°F), according to climate models. After considering urban heat-island bias and other data uncertainties, the best estimates of the observed 100-year global warming rate falls just short of this range.

Climate fluctuates on many time scales. Some scientists, like Dr. Lorenz at MIT, have shown that a nonlinear system like the climate system may be able to produce rapid changes of temperature of magnitude similar to what we have observed in the recent decades. In fact, a recent model simulation by NASA's Dr. Hansen depicts a rapid change of temperature of the order of several tenths of degrees celsius without any changes in the external forcings of the system. General global warming since 1973 must be examined in context with these types of fluctuations.

The chaotic nature of climate could produce climate fluctuations which give the appearance of either a stronger or weaker greenhouse effect. Recent work indicates that these fluctuations make it exceedingly difficult to relate ongoing temperature changes over decades to a specific cause without a clear prior prediction of why such a fluctuation should occur.

In conclusion, given all the uncertainties at the present time, I submit that the observational record cannot be used to validate model predictions of a 1.5 to 4.5°C (2.7 to 8.1°F) warming with doubled carbon dioxide concentrations in the first half of the 21st century. This does not mean that the data invalidate the hypothesis. Instead, it implies that we must continue to improve our theoretical understanding of the climate system, protect the integrity of our climatic data bases, and continue our global data-recovery efforts. These actions will ensure our ability to perform that critical third step of the scientific process -- to verify our climate-change hypothesis with accurate physical measurements. Only then can we objectively assess our predictions and modify our estimates of global warming associated with the greenhouse effect.

SUMMARY

The National Oceanic and Atmospheric Administration's Historical Climatological Network over North America is one of the best quality-controlled climate data sets in the world. Through extensive statistical analyses of these data, we have made the following observations:

1. The overall increase in mean temperature in the United States from 1901 through 1988 has been 0.2° Celsius (0.4° F.). The rate of increase, however, has not been uniform over time. In fact, the mean temperature of the contiguous United States is better described by a significant warming of over 0.6°C (1.1F) from the turn of the Century to the mid-1930s, followed by a cooling trend of about half this amount since the mid-1930s. The recent string of three warm years, 1986, 1987, and 1988, has not been of sufficient magnitude to statistically reverse the cooling trend apparent in the data since the 1930s.

2. Mean temperatures only tell part of the story. Since the 1950s, daytime highs have decreased in the U.S., while nighttime lows have increased. We have found that these changes may be related to changes in cloud cover.

3. Although climate models do not suggest a smaller greenhouse warming over the United States compared to the rest of the globe, the United States has not experienced warming to the extent predicted by the models. There is some evidence that this, too, may be related to changes in cloud cover.

4. Current climate models predict that global temperatures should have already risen between 0.5 and 1.1°C (0.9 and 2.0°F). However, global climate data now show a temperature increase of between 0.5°C (0.9F) and 0.7°C (1.3°F) over the past 100 years, depending upon the data set used. Due to urbanization, it is likely that the overall global warming is significantly less than indicated from certain data sets. In two global temperature data sets we found the urban "heat-island effect" produces a warm bias of 0.2 to 0.4°C over the United States. While the magnitude of this bias for other parts of global land-based data sets is unknown, urban heat islands are not unique to the United States.

5. Climatic observations to date cannot validate or invalidate model predictions of dramatic greenhouse warming for the first half of the 21st century. Contrarily, these observations underscore our lack of understanding of both natural variability and the planet's response to increasing greenhouse gases.

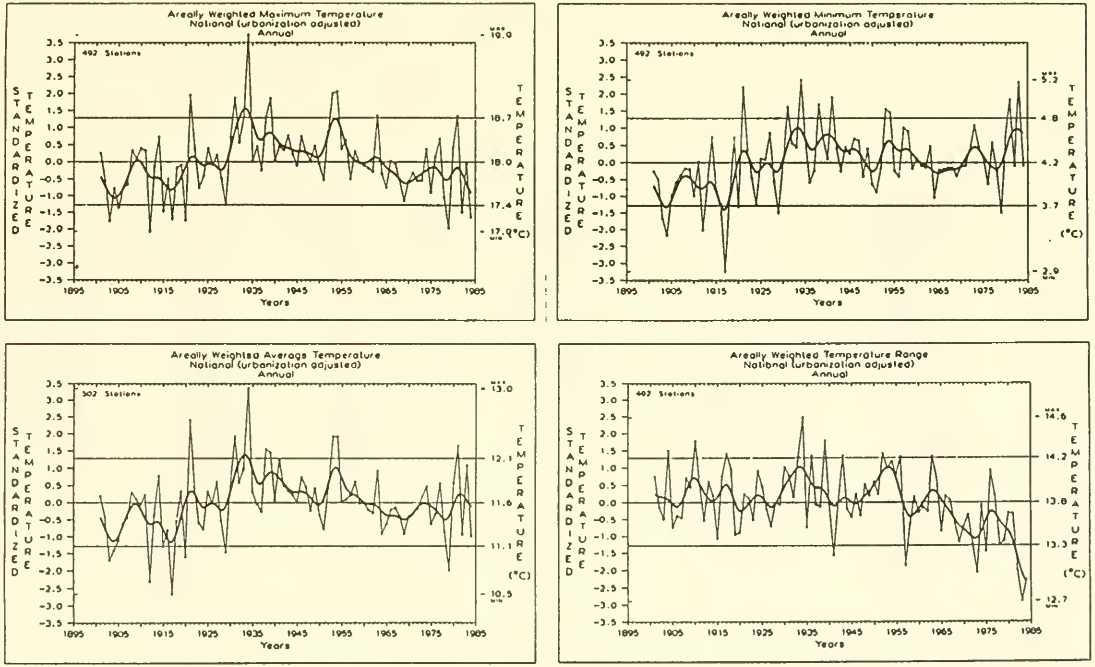
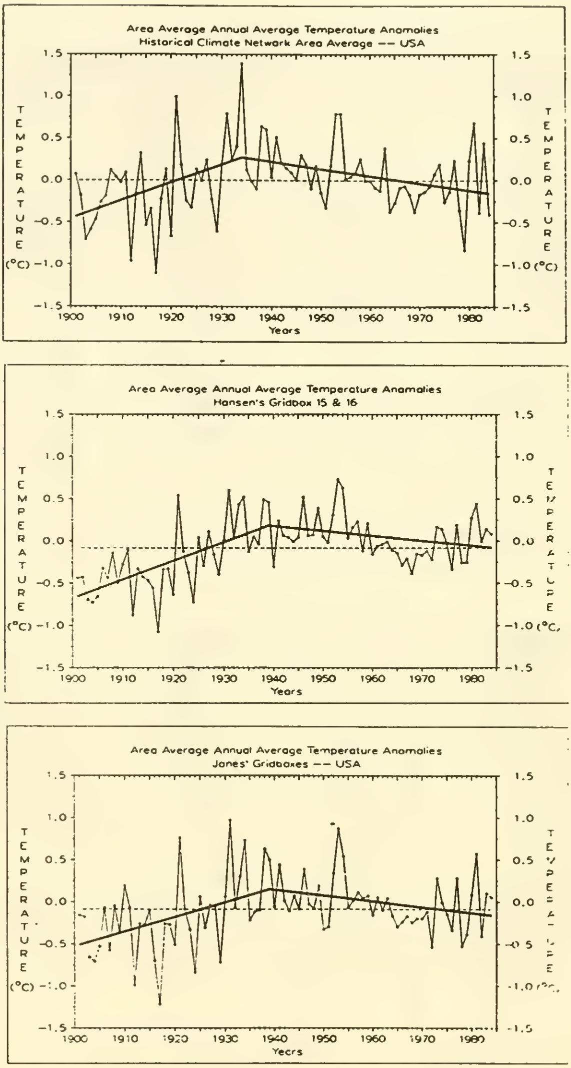


Figure 1 The annual temperatures (right vertical scale) of the daily mean maximum, minimum, and average temperature along with the daily temperature range (the difference between the daily maximum and the minimum) for the contiguous United States. The solid curve smoothes out much of the year-to-year variability. The long-term mean is reflected by the middle horizontal line (0.0 standardized departures, scale read at left) and much above (below) normal temperatures are reflected by points falling outside the horizontal lines associated with standardized departures of 1.282.



Area Average Annual Average Temperature Anomalies
Historical Climate Network Area Average -- USA

Area Average Annual Average Temperature Anomalies
Hansen's Gridbox 15 & 16

Area Average Annual Average Temperature Anomalies
Jones' Gridboxes -- USA

Figure 2 The annual temperature deviations in the United States from the 1901-84 averaging period for three different data sets: the U.S. Historical Climate Network (HCN), the Hansen data, and the Jones data. Statistically significant trends are depicted by solid lines.

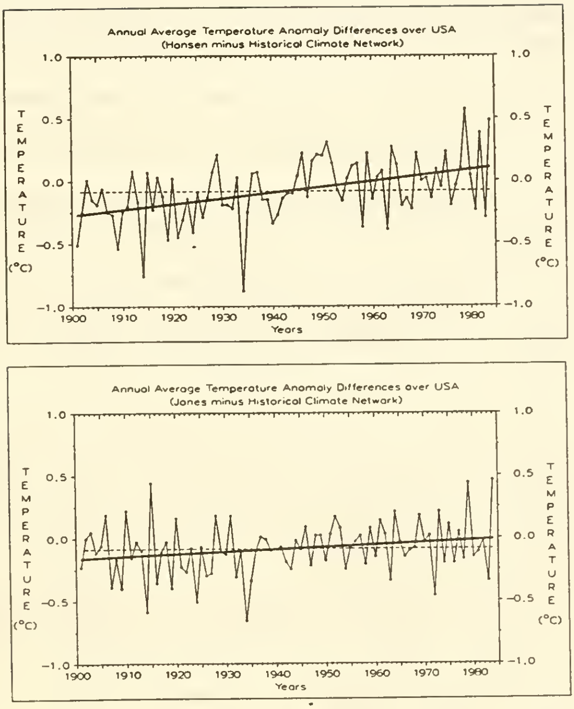


Figure 3 The difference between the annual temperatures of the Hansen minus HCN data and the Jones minus HCN data sets. A statistically significant positive trend is indicated by the positive slope of the solid straight line.

Mr. SHARP. Thank you very much. We will wait one moment until I get word as to whether we are going to get that machine set up so it is usable. Dr. Schneider, you are suggesting by your facial expression——

Mr. SCHNEIDER. If we could show that on a wall, that would be all right.

Mr. SHARP. Judi is checking right now. We will just wait about 2 minutes here.

Mr. SCHNEIDER. I can say a few things while we are going so I don't waste the committee's time while we are waiting for the high technology to arrive.

Mr. SHARP. All right. Why don't you go ahead, Dr. Schneider.

Mr. SCHNEIDER. Thank you. As is often the case in human affairs, it is frequently the administration rather than the technology that hits a snag.

STATEMENT OF STEPHEN H. SCHNEIDER

Mr. SCHNEIDER. Mr. Chairman, it is a pleasure to appear again before you. You may recall that it is nearly 4 years to the month when you had a hearing previously on the subject of the greenhouse effect and, I think, acid rain as well; the overall question of global scale atmospheric pollution.

It is a special pleasure for me to see so many of your colleagues because it was much lonelier for you, I recall, back in 1985 sitting up there alone relative to today. Also I have noticed some people standing in the back, which was a pleasure that we didn't have back in 1985 at that testimony nor at a number of others I had participated in over the last 14 years.

Mr. SHARP. The rooms were empty, I think.

Mr. SCHNEIDER. I was about to say the audience about rivaled the panel in size.

Why is it then, I will ask, and I think we know the answer, that there is such attention to this issue now relative to what there was before. I think the answer is obvious and in some senses unfortunate. The obvious part of the answer is the summer of 1988 coupled by the massive media attention, which literally in many articles, and especially on local news programs, juxtaposed the unusual drought and heat of the past summer, with the greenhouse effect.

In fact, a number of things had been predicted for years, and we discussed them in our previous hearing: the possibility of dry zones in the United States, the increasing probability of extreme heat waves, the possibility of extended forest fires, super hurricanes, flooding in India and Bangladesh, and all those events occurred in the summer of 1988. So my business, unfortunately, took on a credibility perhaps beyond that which it deserved.

What happened was that a problem which had 15 years worth of, in my view, good, solid physics that was relatively ignored all of a sudden became credible overnight in one essentially random event.

I think what we have now is the right degree of public attention, perhaps for the wrong reasons, but in the process of any media-driven attention, excesses are not surprising and, in fact, have marked this debate. Some of your colleagues have referred to that as well in their opening remarks.

What I want to do is depart from my normal style of testimony, which is closer to my previous two colleagues—and I am indebted to them for setting up the scientific issues so well and briefly—and instead focus on the assignment you gave me, which is to try to say what is the substance to the media trial, if you will, of the greenhouse effect? Is it warming or cooling, and is, in fact, that even relevant to the basic questions? I will be able to use some slides for that.

Before I do that, get to my assignment, and while they finish setting up the projection equipment, let me say at the outset that what is it that scientists can legitimately do as experts? What they can legitimately do as experts is say something about the likelihood of certain events occurring. In other words, we can talk about probabilities and consequences. Scientists cannot as experts tell people what to do because what to do, of course, is a value judgment that is in the realm, obviously, of our elected leaders to make those decisions.

We may have personal opinions, and indeed I have them. I think you will find when I discuss what the debate is that one of the confusions is the personal views of a number of scientists, and they are entitled to those views, in my opinion, but those personal opinions are often confused, sometimes by them, sometimes by the translation through shortened articles on the media, to where their value opinions and their expertise merge. What we have to do is learn how to separate those two so that the legitimate questions of scientific agreement and debate can be separated from the value choices.

For example, in the past—in about 1 more minute I will be ready to show that when he is ready to set it up—in the past we have seen lots of debate about whether or not the warming of the Earth in this century—and I am sure Dr. Michaels will address this issue much more extensively than I will—has been one-half degree or one-quarter degree or three-quarters degree, Celsius in this case, and what are the complications. That debate, in my opinion, has in a sense been overblown. It doesn't represent the reason for the main scientific concern about a greenhouse effect, which is based on other physical principles.

Speaking of physical principles, it appears that they are about to plug the machine in, and I will walk over there and do my assignment, having stalled adequately for the past 4 minutes.

Mr. Sharp. A very precise, incessant filibuster. We are not in the habit of that.

Mr. Schneider. Let me briefly try to do my assignment, which was to clarify some of the press debate. I apologize to those people in the audience behind the projector. I am not sure that this would enlighten you that much.

Let me start with a typical kind of an article that followed in the wake of the stories that appeared in the 1988 period. I remember being on a trip in Phoenix, AZ and it was 115°F that day, 1°, I think, short of the all-time record, and I watched on the evening news that night the discussion of the heat wave, and in the same breath, of course, the greenhouse effect was mentioned.

Now, it is not unnatural and it is logical, I would suppose, that given the 15 years we have been talking about this issue, for people to make that association. But generally the direct association was never made by any scientists I am aware of. It was mostly made in the media, and therefore it provoked an understandable reaction from a number of scientists such as Pat Michaels, who will be up next, who are angry about the fact that that association was, in fact, overstated, which I think it was.

The problem is you have got articles like this: "Greenhouse Effect, Hot Air in Lieu of Evidence." This was written by a statistician at Woods Hole named Andrew Solow. I could live with most of what he wrote since scientists are certainly entitled to argue about evidence and that is appropriate. That is, in fact, the scientific method. "But statements at congressional testimony and interviews in the press are not subject to peer review, and that is how unsubstantiated and misleading statements come to dominate public discussion," which was a quote from his article. That I don't like because it is innuendo and based more upon extrapolation of the media coverage of hearings rather than anything else; plus no one is named.

He goes on to say, "And some will say that if we wait until we are sure about climate change, it will be too late to do anything about it. This argument applies equally to an invasion by aliens from space." Now, indeed logically I happen to agree it does apply equally. There is only one problem. If you recall at the outset in my filibuster I said that it was incumbent on scientists to say something about consequences but also probabilities, and I would say that most scientists would not consider the probability of an invasion of aliens from space equivalent to that of a major change of climate in the future.

One is probably 1 in 10 million, whoever knows what the odds are of alien invaders, and the other one is better than flipping a coin. So what science can say something about, as I said, is probabilities and consequences, and that is what we have to do.

Another article appeared recently in the Washington Post on January 8 by Pat Michaels and I won't spend much time on it, because he will talk about it himself. The title—and I don't know, Pat, whether it was yours or theirs because usually—he is shaking his head that it was not his. Usually titles, even on your own articles, are given to you by the journal. It was the "Greenhouse Climate of Fear." In it Pat raises a number of legitimate scientific arguments. I might come out differently from Pat on some of the details, but I think the points are certainly legitimate to be raised. How relevant they are to the greenhouse effect debate I will come to at the end.

One point was in connection with Dr. James Hansen's testimony, very famous testimony in front of the Senate Energy Committee, that there was a "99 percent chance" that the warming of the 1980's—not the drought—was caused by the greenhouse effect—he never said that; he said the warming of the 1980's would be associated with the increase in greenhouse gases. I commend Pat for mentioning names as opposed to innuendoes. He argued that there was a cooling in the Pacific and maybe 1988 wouldn't be the warmest year even though Hansen had speculated in June it might be.

Pat also mentioned that a number of scientists, Jerome Namias at Scripps Institution of Oceanography, and Kevin Trenberth, a colleague of mine at the National Center for Atmospheric Research, were arguing that the drought, which was caused by an unusual pattern in the jet stream, was, in fact, due to an unusual pattern of ocean temperatures. Indeed that was true that people were arguing that.

He went on to suggest that Tom Karl, who I believe has a written statement before this hearing, had pointed out that the effect of heating in cities, since cities have grown up around thermometers and cities produce heat, that that led to some artificial warming in the record. This so-called urban heat island effect has been known for many, many years, and both Hansen and the British group, the Wigley and Jones group, have known about this and have tried to correct for it, but Tom Karl had a better data set and made some corrections of his own.

Pat made one statement which we will let him talk about later where he said that:

> If the effect of urbanization artificial warming on the temperature record averages the same over the rest of the world, and there is no reason to believe it doesn't, then there may have been no global warming to speak of during the last century. Karl's finding surprised none of us who daily toil with the data, but it should be a major shock to those who are using those figures for policy purposes. Is it irresponsible to point this out in public?

I will answer that, Pat. No, it is not.

But there is more confusion, no doubt, if you read another article. This is "Research News" in Science, an article by Richard Kerr. I don't know whether he is responsible for the title, but it says "The Global Warming is Real." In it he quotes Tom Karl to the effect that:

> The long-term global warming is something on the order of 0.4°C during the past century. Is the bias 0.05°C or 0.2°C? The chances that it is the same as the warming are pretty remote. It is a matter of adjusting the rate of rise, not questioning the rise itself.

Tom Karl told me when he was out at my institution recently that he was inundated by a number of press calls wanting him to essentially be the antigreenhouse person. He said:

> That's not what I am. I'm just simply trying to get the numbers right and the data, and no matter how I massage them, I can't make an overall global trend disappear.

He also was not arguing that he was trying to make it disappear; just simply doing what a scientist is supposed to be doing, which is trying to assess the magnitude of the numbers.

Here is the Trenberth article to which Pat Michaels referred as well as a number of other people. I was distressed when this article appeared because headline after headline plus coverage in the electronic media said—I recall one headline saying "Summer of 1988 not Caused by Greenhouse Effect After All." What distressed me was that I don't know any scientists who said it was.

Well, what Trenberth said that I wanted to point out here is:

> Climate simulations indicate that a doubling of carbon dioxide concentrations could increase the frequency of summer droughts over North America. Thus, the greenhouse effect may tilt the balance such that conditions for droughts and heat waves are more likely, but it cannot be blamed for an individual drought.

Recently James Hansen, who wrote a response to the Solow article in the New York Times, said—I will quote that, too. It is in my written testimony if anybody wants it:

> As I testified to the Senate during the 1988 heat wave, the greenhouse effect cannot be blamed for a specific drought, but it alters the probabilities. Our climate model, tested by simulations of climate on other planets and past climates on Earth, indicates that the greenhouse effect is now becoming large enough to compete with natural climate variability.

In other words, the actual difference between what Trenberth said and Hansen said was very little, yet there were differences in their views, but the differences were extrapolated, in my opinion, not through a conspiracy but through the natural tendency in the media to focus on debate. It is more exciting.

You get the general idea. I will do two more quickly. Here was an article, a good article by Philip Shabecoff in the New York Times, and he didn't write the headline either, "U.S. Data Since 1895 Failed to Show Warming Trend." That was January 26, 1989, and lo and behold, on February 4, here is an article by Phil again, "Global Warmth in 1988 Is Found To Set a Record." So if any of you are confused, I am not surprised.

He points out that Phil Jones at the University of East Anglia has argued that including urban heat island corrections and other details—which are, by the way, not easy to work out, as you will hear shortly—it suggested that 1988 was, in fact, the warmest year on record, followed by 1987, 1983, 1981, 1980, and 1986.

Now, is it legitimate to say that the United States hasn't been warming and therefore there is no trend? I would argue it is as legitimate to say that, no global trend, as it would be—and I will put this up here to predict the outcome of a U.S. Presidential election by looking at only a few States. This map shows in green the States that voted Democratic in the 1976 election. The blank are the ones that went Republican. The United States is less than 2 percent of the world's area. So to try to figure out what happened in that election, what you would do is pick two States and then try to guess the trend, two States at random.

Clearly it is irrelevant, from the global point of view, what happened in two States. You obviously have to have a much larger sample in order to know who won the election. But supposing I picked 1984. In 1984 you will notice there is only one green State, so in fact that is the reason why I colored in the Democratic States. It was less work.

If you had picked any two States at random, you had a pretty good chance that you would have gotten the global average, if you will. So what is the metaphor? The metaphor, in a sense, is obvious. It is that if there is a very small trend, like one-half degree Celsius global warming, you are not going to learn much by looking at one region over one decade on 0°. You need much longer-term averages over much wider spaces to be able to have any confidence.

On the other hand, if there is a very large signal, like 2° warming on a global basis, you would be very surprised if an area the size of the United States didn't follow that trend. There may be one exception, but the number of exceptions will recede as the signal grows.

The metaphor I like best is dice. I have been using this for many years. If you ask what is the probability of 5 above-95° days in a row in Washington, DC in July and you go through some statistics, you come up with a number that is something on the order of one in six, like one face of a die. Now, if you warm up by 3°F and you don't change any of the other characteristics of the climate, just simply the average, then the odds go to something like three in six, three faces of the die. But if you roll it twice, that isn't going to tell you anything. You could get two hot ones and it wouldn't prove the greenhouse effect.

What happens is the more you roll, the clearer the odds become. The problem is, and this is where the value arguments get buried, the problem is if we wait to roll it long enough to find out what is really happening, we do that at the risk of having to force us and other living things to adapt to a larger dose of change. That is where the policy debate comes in because it isn't a question of scientific certainty; it is a question of what kind of risks do you want to take with the planet. That is where odds and probabilities in these debates become important.

Finally, let me finish with saying what is it that we really know? What can we say about it? One thing we know for sure is the greenhouse effect is not on trial in the scientific community. It is about as well accepted a proposition as there is in the atmospheric sciences. Pat's article says that. Fred Singer's article says that. I don't know anyone competent in atmospheric physics who has disputed that.

I won't go over what I have shown on the board, but we can put numbers on where the energy goes and so forth. There are literally millions of observations in space and in laboratories which tell us that changing certain gases in the atmosphere will trap heat near the surface.

The debate begins to brew over two areas, and we have policy control in one of them. One is what will the trace gas component in the future be, and that is an area where this committee can have some impact. First, if we try to project forward, what we are looking at here is present carbon dioxide concentration around 350 parts per million, preindustrial value around 280, and mythical doubling of CO_2.

When does that doubling occur? Well, if energy use grows at 2 percent per year, according to these charts, which assumes that half the CO_2 stays in the air, then CO_2 doubles sometime in the middle of the next century. If it grows at 1 percent per year, then it is stretched out to the century after that. You can even have a negative growth scenario, which Amory Lovins proposed, where you reduce energy use by 2 percent per year and that stabilizes CO_2. If you grow at a very high rate, like 3 or 4 percent growth per year, then you can double early in the next century.

What causes this, of course, as we know, is the use of coal, oil, and gas. Coal puts out twice as much CO_2 as gas, so what you need to do is what Paul Ehrlich and John Haldren called in 1971 as the "population multiplier." The total CO_2 emissions is the CO_2 per technology times 20 other factors. As I said, coal is twice as much as methane, and nuclear and solar are zero except for the amount of energy it takes to build or decommission the plants. You can't leave that out. So we have control over engineering.

The second term is technology per capita. Well, that is politically volatile stuff. That is standard of living. The third term is population size. This is not an ideological equation; it is a statement of the conservation of mass: simply that the total emission is engineering times standard of living times population. That means it is impossible to know the future specifically because we don't know what is going to happen. That is the bad news.

The good news is that it does say that we have three areas where, if we chose to, we could have policy impact. Whether to choose it is a value choice, of course, but we could choose to have policy. We could work on any of those three if that were our desire and have some influence over the outcome.

What do climatologists do, recognizing those wide uncertainties? They usually assume three different values: a high, a medium, and a low growth scenario. They then add all the uncertainties due to their own sphere, which were mentioned earlier by my other colleagues. Even though I am a climate modeler and I'm not going to talk about them, there is about a factor of 2 to 3, in my opinion, uncertainty over the global projections. So what climatologists typically do is produce charts like this which show global temperature change over time, 0°C, 1°C, 2°C, 3°C.

Just to give you perspective, 5°C is the temperature change between the end of the last ice age and the present. Two degrees is about as warm as the planet has been during the era of civilization, this past 10,000 years. There are three scenarios. This comes from an international assessment. There is a low one, where the globe doesn't warm up much more than one-half degree; a medium one, where it warms up to something on the order of 3° by the end of the next century; and a high one, which I would not hesitate to call catastrophic, where it warms up to 5° in the timeframe of less than a century.

What are the probabilities? These are the consequences. What are the probabilities of these scenarios? I wish I could tell you. Our models are very cloudy crystal balls. I would only simply say that I can give you intuitive ones based upon my reading of the evidence. You can't quantify that uncertainty. Presumably this one and this one, the high and the low one, are relatively low, 10 percent. I don't know. Who knows how to really assign that? The middle one, 50 percent? Flipping coins?

It is difficult to know the numbers, but it could be in that range. It is not even impossible that it could be worse than that or even further down. It is just simply as you get further away from the middle scenario, the probability gets lower.

Finally, why would we pay any attention to the past 100 years? Is it really important what has happened in the last century? My argument is: not really. What has happened in the last century is scientifically interesting, but the magnitude of the change is not large enough that we can really draw much inference pro or con about whether the 25 percent increase of CO_2 is proved or disproved. It is like trying to figure out what the odds in a die are by rolling it six times. You have got to roll more.

What gives us confidence, then, to get up in front of you, as I have done many times, or other groups saying that we should pay serious attention to the future? Well, we have ways to validate these models, and it is the physics I was referring to in my opening filibuster, not the performance of the planet in the past century that gives me confidence.

What this map shows is a very important natural experiment, the temperature difference between winter and summer. This is a model and an observed result. The model is from the Geophysical Fluid Dynamics Laboratory, a NOAA laboratory in Princeton, NJ, by S. Manabe and coworkers.

Here let's look at the observed map first. If you take a look, you find a 50°C temperature difference in Siberia between winter and summer. It's definitely an extreme change, maybe only 2° to 5° in the middle of oceans, 10° in Australia, about 20°C to 40°C in our country.

How well does the model do? Well, what you are seeing in this graph is very typical of models. The basic overall zonal and sort of continental-scale patterns aren't too bad, but the exact regional details don't agree well. They do reproduce the 40° but not quite 50°. The 10° around Australia is nicely reproduced.

This is not direct validation but surrogate validation. You are changing the amount of energy from winter to summer. We all know what makes the seasons work. The question then is how well do the models do? The answer is they do pretty well. They do better than a factor of two. Now, if we made a major mistake in how we treat clouds and so forth, it would be very difficult to get it to come out as well as it does.

The physicist in me is distressed because we are getting reasonably decent—and when I say reasonably decent, I mean to some factor of two, maybe three—answers for reasons that we don't entirely understand, and that is very annoying. The engineer in me, since I was trained in both, is happy that we have at least some calibration and the models are not crazy.

The bottom line, then, is what we are doing is changing the envelope of gases over which people are certain there has to be a change in the heating of the Earth. No one is disputing that. No one is disputing the changes in those gases or their origins either, although we argue a bit about the numbers. Where the debate comes in is what is the magnitude of global change and the timing, and that typical 1° to 4° range represents not all possibilities but maybe 80 percent of the scientific community.

The press debate often focuses on the 20 percent that is on the outliners because it is more exciting rather than in the middle, and we need to make sure we don't lose sight of the fact that the vast majority of scientists sees certainly an even odds, first decimal place odds that there could be change of the magnitude of several degrees into the next century, perhaps as much as 5°.

What that says is that we could be changing the climate by as much change as it took from the end of the Ice Age to the present, which took 10,000 years. We could be doing that in a century, and that is what has me personally concerned. We are insulting the environment, as was said by our colleague at the front, at a much faster rate than we are understanding what we are doing. Whether we should tolerate that without some attempt to slow it down is the value judgment that we have to face.

In my value system, what we need to do are the kinds of actions that have a fairly large constituency anyway and to follow the basic sound economic principle of high leverage, what we call the tie-in strategy. Don't do an action that simply operates to slow down the greenhouse effect by itself, but try to pick those things that make some sense even if the whole greenhouse effect weren't true. Energy efficiency is mentioned by everybody, development of renewable alternatives and so forth.

I would argue that what the greenhouse effect does is gives you additional reason to do those things, and given that uncertainties can cut two ways—remember, the uncertainties are just as likely to make the high scenario come true as the low scenario. You also are buying insurance, in this case planetary insurance against catastrophic change, and in my personal view, in my value system, that is worth spending some present capital on. Thank you.

[Testimony resumes on p. 78.]

[The prepared statement and attachment of Mr. Schneider follow:]

Testimony of

Stephen H. Schneider*
National Center for Atmospheric Research**

GLOBAL WARMING:
SCIENTIFIC REALITY OR POLITICAL HYPE?

The summer of 1988 saw a combination of events that quite literally catapulted the "Greenhouse Effect" out of ivy-covered halls of academe and the glass and stone of government offices into the public consciousness. Major drought, intense heat waves, forest fires, a super hurricane, and flooding in Bangladesh -- all the kinds of events that had long been forecast as associated with global warming from increasing greenhouse gas buildup -- occurred in that year. For months, magazine covers, news broadcasts, and newspapers were blanketed with stories of the extreme weather. These were often juxtaposed with stories on the greenhouse effect. It would be hard for an unscientifically trained listener or reader to have concluded anything other than that there was an intimate connection between the bad weather of 1988 and the buildup of greenhouse gases that had been increasingly discussed by a number of scientists (myself included)[1] for more than 15 years. Was this finally the proof that these academic warnings had indeed come true? On June 23, 1988, Dr. James Hansen of NASA's Goddard Institute for Space Studies (GISS) stated in front of the Senate Energy Committee that he felt that there was a "99%" chance that the unusually warm globally averaged temperature records he and a colleague had constructed for the 1980s could not have occurred by chance but rather were the result of the buildup of greenhouse gases.[2] He went on to point out that increasing the global temperature would increase the likelihood of extreme heat waves such as those that were occurring in 1988. He never said that the particular individual drought of 1988 could have been caused by the greenhouse effect, only that such events would increase in likelihood as the planet heated up -- not a very controversial view, and one that had been voiced by a number of others (myself included)[3] over the past 10 years. Unfortunately, the widespread publicity following the drought in general and that hearing in particular erroneously led to the impression that Hansen and many other climatologists believed that the greenhouse effect was responsible for the drought conditions in 1988. Neither Jim Hansen nor any other qualified atmospheric scientist I am aware of has ever made such a statement. For example, in a recent letter to the New York Times Hansen commented that "as I testified to the Senate during the 1988 heat wave, the greenhouse effect cannot be blamed for a specific drought, but it alters the probabilities. Our climate model, tested by simulations of climate on other planets and past climates on Earth, indicates that the greenhouse effect is now becoming large enough to compete with natural climate variability."[4] Hansen did, however, suggest that the warming trend in the 1980s was very likely to have been caused by the greenhouse effect, and that "99%" statement was often confused with the idea that the drought was caused by global warming. The latter is obviously absurd, given that the amount of greenhouse gas increase from 1987 to 1988 is very small relative to the major climatic difference between those two years.

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* Any opinions, findings, conclusions, or recommendations expressed in this testimony are those of the author and do not necessarily reflect the views of the National Science Foundation.

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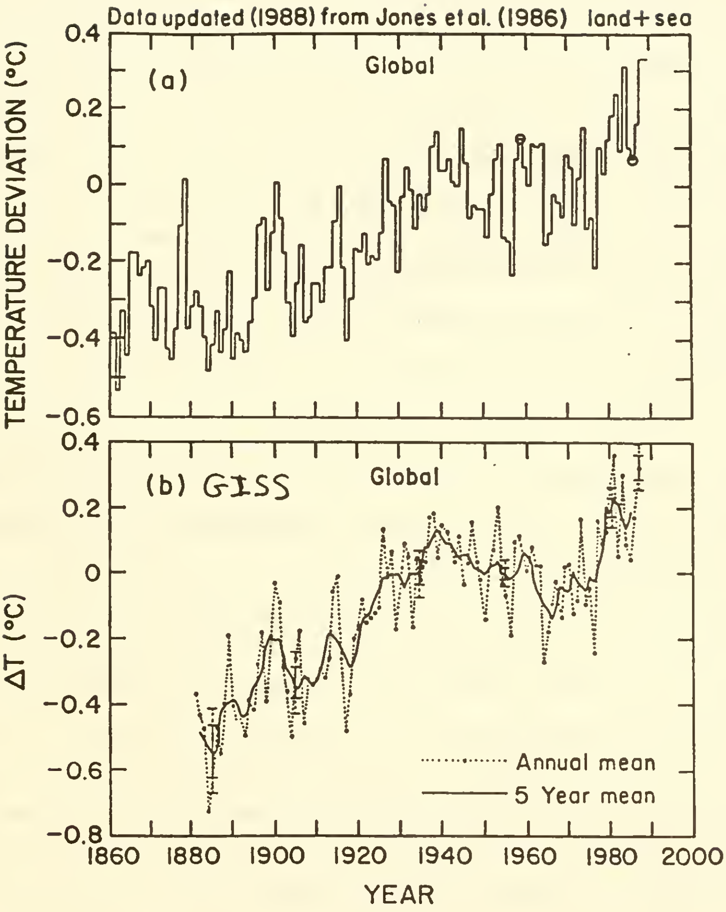
The strongest statement one could make responsibly, given the uncertainties, is that increasing the global average temperature could increase evaporation stress, thereby slightly altering the odds toward increased drought. However, as is well known by all atmospheric scientists, droughts are generally a result of unusual patterns of atmospheric circulation, whose causes are not clear cut and most often are ascribed to unusual temperature patterns in the oceans. Later in 1988 that hypothesis of cause and effect would indeed be reaffirmed by calculation made by Kevin Trenberth and colleagues at the National Center for Atmospheric Research. Unfortunately, many atmospheric scientists were unaware of the exact statements made by Hansen and others who had testified at various hearings during the 1988 summer, and therefore they accepted the widespread perception reported repeatedly in the media that such witnesses believed the greenhouse effect and the drought were cause and effect. This misperception caused an angry and understandable counterreaction. For example, the U.S. National Climate Program office helped to sponsor a workshop on climate trends at the National Academy of Sciences that took place on 29 September 1988. It focused, for example, on a number of difficulties with the observational record used to reconstruct global temperature trends. These include the fact that many thermometers have had cities grow around them which causes an unnatural urban heat island effect. Other errors were noted, such as stations that had moved out to airports or up or down mountains, etc. Shortly I will discuss the seriousness of these issues.

At the same time that this meeting was taking place, the calculations by Trenberth and colleagues were announced. These suggested that unusually cool surface temperatures in the equatorial Pacific (actually, the cool water was flanked by warm water) may have been responsible for distorting the jet stream thereby steering storms up and out of the United States in the spring of 1988 and contributing to the intense drought in the summer. This result was frequently cited in headline after headline to the effect that "Drought of '88 not caused by greenhouse effect after all". Of course, Trenberth never accused any scientists of saying that it was, but the widespread association that was created from the summer's coverage thereby led to a backlash that was, in essence, an artificial debate. For example, in their Science article, Trenberth and colleagues quite rightly argue that "climate simulations indicate that a doubling of carbon dioxide concentrations could increase the frequency of summer droughts over North America. Thus, the greenhouse effect may tilt the balance such that conditions for droughts and heat waves are more likely, but it cannot be blamed for an individual drought."[5] That statement is clearly reasonable and quite consistent with those of Jim Hansen, myself, and most other scientists I am aware of who speak on this issue.

The trial by media of the greenhouse effect was thus a nonscientific issue from the very beginning. Nevertheless, many Op Ed pieces continue to appear from scientists and others criticizing the "hysteria" being generated by some (usually unnamed) public scientists on this issue. For example, S. Fred Singer published a piece in the 30 August 1988 Wall Street Journal entitled, "Fact and Fancy on the Greenhouse Effect", and Woods Hole Oceanographic Institution statistician Andrew Solow had a small piece in the 29 December 1988 International Herald Tribune entitled, "The Greenhouse Effect: Hot Air in Lieu of Evidence." But the most visible recent such article, I believe, was by University of Virginia climatologist Patrick Michaels, whose article "The Greenhouse Climate of Fear" appeared in the Op Ed pages of the Washington Post on 8 January 1989. He lists a number of issues which he believes were improperly or underreported in the press, giving examples of "a few recent revelations that somehow got lost with the ozone". He disparaged Hansen's June testimony forecasting that 1988 would be the warmest year on record, even though recent evidence now suggests that indeed it was.[6] Michaels goes on to refute the greenhouse explanation of drought by citing Trenberth's work to the effect that the drought of 1988 was caused by cold tropical ocean temperatures,



A comparison of the global surface temperature trends of the past 100 years constructed from land and island stations and ocean surface temperature data sets at the (a) Climatic Research Unit and from a similar set of stations (minus the ocean surface temperature data set) at the (b) Goddard Institute for Space Studies.

FIGURE 1

something that was never doubted by other scientists. He cites the very recent results of NOAA scientist Tom Karl, who, Michaels says, "arguably knows more about regional climate variation than anyone in the world." Michaels describes Karl as saying that the NASA-GISS calculations for warming over the United States were too high by nearly 1°F this century because of the urban heat island effect. Because of this, Michaels continues, "there may have been *no* [his italics] global warming to speak of during the last century. Karl's findings surprised none of us who daily toil with the data. But it should be a major shock to those who are using those figures for policy purposes. Is it irresponsible to point this out in public?", Michaels argued.

The results of the Goddard Institute for Space Studies (GISS) and Climatic Research Unit (CRU) are reproduced here as Figure 1. The GISS record shows a warming of a little over 0.8°C in the past 100 years and the CRU record a global warming of about 0.65°C over the same period. Both include some of the same thermometers, but the CRU record adds an oceanic data set not included in the GISS record. Both groups were aware of and had attempted to account for the artificial heating in urban areas due to the growth of cities around such thermometers during the past century. The question, therefore, is how well were they able to make corrections for this urban effect, and does it indeed, as Michaels implied, invalidate the notion that the globe has been warming for the past century? Neither of these groups had easy access to the vast network of rural stations that Tom Karl at the National Climate Center in Asheville, North Carolina did. Therefore, Karl was able to check the accuracy of predictions of temperature trends in the United States made by both the GISS and CRU groups. What he found was that the GISS results had overestimated the warming trend in the U.S. by a little less than 0.4°C (30% less of an error than Michaels implied), but the East Anglia group had only overestimated it by about 0.15°C Karl found. This GISS global record suggested a warming of over 0.8°C in the past 100 years, and the East Anglia group about 0.6°C or so. Therefore, if one makes the very conservative assumption that the entire world record suffers as strong an urban heat island bias as the United States, and thus applies Tom Karl's corrections to the global record (even though they only apply to the United States), then that correction procedure simply reduces Hansen's record and the CRU record to about 0.5°C (.9°F) global warming for the past century. This is not consistent with the frequent statements in the press and on Op Ed pages that urban biases are likely to eliminate the global warming trend over the past century. Moreover, this is not believed by Tom Karl or any other knowledgeable atmospheric scientists I am aware of. For example, in an interview with Science magazine's science writer Richard Kerr, Tom Karl commented that "the long-term global warming is something on the order of 0.4°C during the past century. Is the [urban] bias 0.05°C or 0.2°C? The chances that it is the same size as the [global] warming are pretty remote. It is a matter of adjusting the rate of rise, not questioning the rise itself," Karl told Kerr (Science 243, 603, 1989). I know that Tom Karl has been frustrated by the frequently cited implication that he somehow believes otherwise.

Another example of an overblown debate with little relevance to global warming occurred in mid-January when a number of Department of Commerce scientists (including Tom Karl) published a U.S. temperature trend record that got widespread press coverage. They pointed out that there had been no net warming in the United States over the twentieth century. This, too, was greeted with many headlines that the greenhouse effect has not happened in the United States. Good articles (albeit with questionable headlines) appeared on this subject,[7] quoting a number of sources, including the authors of the North American study, to the effect that the United States occupies only a few percent of the world's area, and that there are continental-sized regions that have been warming substantially, as well as continental-sized regions that are cooling over the past few decades. Therefore, it is just as foolish to draw global inferences from looking at the small fraction of the Earth represented by the U.S. as it would be to try to predict the outcome of a national election by looking at trends in only one or two states. Nevertheless, an artificial debate has grown over the validity of the greenhouse effect as a result of this publication.

What then, has the debate visible to the public to do with the actual scientific debate? I'm afraid the answer is often "too little". Virtually all atmospheric scientists believe that the greenhouse effect as a scientific proposition is well established and essentially beyond question. Pat Michaels also acknowledges this in his article, as does Fred Singer. The trapping of heat near the Earth's surface from the presence of gases such as water vapor, carbon dioxide, methane, and chlorofluorocarbons has been established from literally millions of measurements over the past century. It is also beyond debate that carbon dioxide has increased about 25% since the industrial revolution, and methane substantially more than that. It is also virtually certain that the CO_2 increases are attributable to human activities, principally, the burning of fossil fuels and deforestation. There is controversy, but it begins to develop over how much trace gases will increase over the next century. Given typical assumptions of growth in fossil fuel use, population, and standards of living into the future, the uncertainties in the greenhouse gas projections are roughly a factor of 3. Uncertainty in the global climate response to a given increase in trace gases in also typically a factor of 2 to 3. Taken together, these uncertainties explain why most national and international assessments suggest that a warming somewhere from as little as one degree to as much as 10°C (1.8 - 18°F) is possible by the end of the next century.[8] There are a few who believe that warming could be even more than that or that a cooling could be triggered, but these views represent a very small segment of scientists. Major assessments put the most probable global temperature increase over the next 50 years or so at several degrees Celsius.[8]

Less certain than projections of global average temperature increase is the regional distribution of climate changes. Such changes could have major impact on water resources, agriculture, human health, navigation, or coastal planning.[9] Whether predictions of drying in the midcontinental United States and loss of comparative advantage for U.S. agriculture, which are frequently inferred from climatic models, will be true is simply not known now. At the present state-of-the-art, I doubt that reliable forecasts of regional climatic changes will be available much before 20 years. That distant date might be accelerated substantially if both present and expanded research efforts were carefully organized, but even then, we cannot guarantee scientific consensus on the reliability of regional predictions of climate change, even on the time frame of a decade. But I believe it is worth a try to make the effort to improve the reliability of regional climate predictions, for such information would help to put evolving policy making on a firmer factual basis.

Finally, the greatest lack of scientific consensus occurs over whether present uncertainties justify an immediate policy response -- a value judgment, not an issue resolvable by scientific methods. Whether a certain amount of knowledge justifies urgent action or delay depends on whether one fears more investing present resources as a hedge against future change than one fears future change descending without some attempt either to slow it down or make investments to adapt to it more effectively. In my value system, the latter is a clearly preferable course, for I am a believer in insurance against potential catastrophic loss at both personal and national levels. I am frequently disturbed when anyone argues for or against some specific policy action solely on the basis of some supposed scientific knowledge or uncertainty. For example, in his New York Times and International Herald Tribune piece Andrew Solow mocks those who "say that if we wait until we are sure about climate change, it will be too late to do anything about it. This argument applies equally to an invasion by aliens from space. More seriously, this argument neglects the costs of overreaction."[10] Of course, what Solow neglects to make explicit is that waiting for more evidence before acting is his value position. He also fails (which is surprising for a statistician) to suggest anything about the different probabilities between an invasion of aliens from space and rapid future climate change. In my estimation, space invaders are no more likely than the collision of the Earth with a large asteroid -- which would be a catastrophe! The odds of such a collision are presently assessed at something like 1 chance in 10 million each year. But the odds of rapid, potentially unprecedented -- even catastrophic -- climate change are certainly in the first decimal place of probability, and I believe the likelihood of several degrees C warming by 50 years is a better than an even bet. In any case, the cost of overreaction is a legitimate issue, but so is the cost of underreaction. The policy process is not advanced when such issues are ridiculed with hollow rhetoric. Instead, scientists should be asked to provide what they are technically competent to offer: estimates of specific consequences of greenhouse gas buildups and their likelihoods of occurrence. Any statements beyond that are the personal opinions of those scientists. Although I believe that scientists, like all citizens, are entitled to opinions on how to deal with those probabilities and consequences, we must always be scrupulous to point out that such opinions are personal value judgments.

Finally, the more rapidly climate changes evolve, the more difficult it will be for societies to adapt; and it may be impossible for natural ecosystems to adapt without substantial dislocations or extinctions of some species. The more rapidly greenhouse gases build up, the more difficult it will be for scientists to forecast the outcome reliably. The less we know about the future the less easily we will be able to adapt -- or even take advantage of some of the changes that will occur. Quite simply, the "bottom line" of the evolving greenhouse gas buildup is that we insult the environment at a faster rate than we can predict the consequences, and that under these conditions, surprises are certain.

In order to establish that the greenhouse effect signal has clearly been detected in the climatic record, it is my view that another decade or possibly two will be required to be sure that the warming of the 1980s (which do appear to be the warmest decade recorded on a global basis) will in fact continue into the 1990s and beyond. (I expect it will, but I can’t prove it, of course.) If we choose to wait for that added degree of certainty, then this is not a cost-free delay, for it must be done at the price of forcing us and other living things to have to adapt to a much larger dose of change than if we were to act today to slow down the change or to invest affirmatively to make our future adaptations easier. Wrangling over a few tenths of a degree in the historic global temperature trends in this hemisphere or that will not change the fact that postponing action is a basic gamble. Furthermore, the nature of regional climate fluctuations and global trends during the past century are very difficult to establish to a high degree of accuracy because of (a) missing or faulty temperature data as well as (b) incomplete data on other possible competitive causes of climate change, such as changes in the energy output from the sun, human dust, or other pollutants.[11] Quite simply, the strongest argument for concern about the rapid buildup of greenhouse gases comes not from the small global climatic trends and large regional climatic noise of the recent past, but rather the well-validated nature of the physical processes that have long been understood to accompany increases in infrared radiation-trapping (i.e., greenhouse) gases. Several pieces of strong, but circumstantial, evidence suggest that climate change over the next several decades could proceed at unprecedented rates. But again, this cannot be demonstrated to have occurred on Earth beyond a reasonable doubt without another decade or two of measurement and research. (And, again, waiting before acting is not a risk-free gamble.)

Finally, it is my personal belief that we clearly know more than enough to actively pursue those actions which both slow down the rate of buildup of greenhouse gases and at the same time help solve other unrelated societal problems -- what has been called the "tie-in strategy". Delaying rapid change can buy us time to adapt more easily and provide insurance against the not remote possibility of catastrophic rates of change. (Of course, present uncertainties are as likely to cause us to underpredict as to overpredict future changes.) In particular, individuals, firms, and nations should pursue those activities that would make general good sense, regardless of whether the greenhouse effect turns out to be much less serious than presently contemplated. For example, stepped-up investments in energy production and end-use efficiency, accelerated testing of non-fossil fuel alternatives, the development of more widely climate-adapted crop strains, adding flexibility to the management of water systems, and coastal planning to deal with rising sea levels and storm surges all contribute to the solution of existing societal problems even without further climate change. Therefore, it seems prudent, in my value system, to consider implementing first those policies which have multiple benefits, including that of buying insurance against the real possibility of large and potentially catastrophic climate change. Obscuring this clear-cut policy debate with false dichotomies or scientific hair-splitting about the nature of past climatic fluctuations -- variations that often are unknowable in detail -- seems to me to detract from the important task of defining what resources need to be mobilized to slow down a very rapid rate of global atmospheric change. I hope that recent shrill or irrelevant debates do not mask the already large scientific consensus that exists over the basic physical phenomena known as the greenhouse effect, a scientific proposition over which I have heard virtually no scientific dissent.

This testimony, so far, has itself been distracted by the recent banter over whether the greenhouse effect is scientific reality or political hype. I regret the need for addressing this side issue at such length -- hopefully I have put it in perspective. In order to present a more orderly and careful discussion of my views, a recent paper published in Science is attached as an appendix. It presents in much more sober tones than this testimony (and with many references) more details on the scientific and policy issues just briefly touched on in this testimony.

FOOTNOTES

1. For example, see Stephen H. Schneider and Randi Londer, 1984: The Coevolution of Climate and Life (Sierra Club Books, San Francisco), Chapter 8, p. 294-365; or Stephen H. Schneider, Congressional Testimony before the U.S. Senate Full Committee on Energy and Natural Resources, 11 August 1988, Congressional Record (in press).

2. James E. Hansen, 1988: Prepared Statement, The Greenhouse Effect: Impacts on Current Global Temperature and Regional Heat Waves. In Greenhouse Effect and Global Climate Change, Hearing before the Committee on Energy and Natural Resources, U.S. Senate, Washington, DC, June 23, p. 42-79.

3. For example, L. O. Mearns, R. W. Katz, and S. H. Schneider, 1984: Changes in the probabilities of extreme high temperature events with changes in global mean temperature, J. Clim. and Appl. Meteorol. 23, 1601-1613, pointed out that if temperatures were to increase by only 3°F, and nothing else in the climate system changed, then the probability of a heat wave in which five or more days in a row in July saw afternoon temperatures greater than 95°F would increase in Washington, D.C. from a present probability of around 1 in 6 to a future probability of around 1 in 2. In Des Moines, Iowa, the respective probabilities would change from 1 in 18 to 1 in 5. These changes in the odds on "climatic dice" are what would be expected if only temperature increased by 3°F.

4. J. Hansen, letter to New York Times, 11 January 1989.

5. K. E. Trenberth, G. W. Branstator, and P. A. Arkin, 1988: Origins of the 1988 North American Drought, Science 242, 1640.

6. For example, in a page 1 story, Philip Shabecoff reports in the February 4, 1989 New York Times that the Climatic Research Unit in East Anglia, England, has concluded that 1988 did, indeed, set a record as the warmest global temperature year.

7. P. Shabecoff, U.S. Data Since 1895 Fail to Show Warming Trend, New York Times, 26 January 1989, p. 1.

8. Please see my recent article, Stephen H. Schneider, 1989: The Greenhouse Effect: Science and Policy, Science 243, 771, for references to many such assessments. It is attached to this testimony as an Appendix.

9. J. B. Smith and D. Tirpak, Eds., October 1988: The Potential Effects of a Global Climate Change on the United States: Draft Report to Congress, Vols. I and II, (Environmental Protection Agency, Washington, DC).

10. Andrew Solow, Greenhouse Effect: Hot Air in Lieu of Evidence, International Herald Tribune, 29 December 1988.

11. See Stephen H. Schneider, 1989: Science, ibid., pp. 775-776.

APPENDIX 1

The Greenhouse Effect: Science and Policy

STEPHEN H. SCHNEIDER

Global warming from the increase in greenhouse gases has become a major scientific and political issue during the past decade. That infrared radiation is trapped by greenhouse gases and particles in a planetary atmosphere and that the atmospheric CO_2 level has increased by some 25 percent since 1850 because of fossil fuel combustion and land use (largely deforestation) are not controversial; levels of other trace greenhouse gases such as methane and chlorofluorocarbons have increased by even larger factors. Estimates of present and future effects, however, have significant uncertainties. There have also recently been controversial claims that a global warming signal has been detected. Results from most recent climatic models suggest that global average surface temperatures will increase by some 2° to 6°C during the next century, but future changes in greenhouse gas concentrations and feedback processes not properly accounted for in the models could produce greater or smaller increases. Sea level rises of 0.5 to 1.5 meters are typically projected for the next century, but there is a small probability of greater or even negative change. Forecasts of the distribution of variables such as soil moisture or precipitation patterns have even greater uncertainties. Policy responses range from engineering countermeasures to passive adaptation to prevention and a "law of the atmosphere." One approach is to implement those policies now that will reduce emissions of greenhouse gases and have additional societal benefits. Whether the uncertainties are large enough to suggest delaying policy responses is not a scientific question per se, but a value judgment.

WITHIN THE PAST YEAR COVER STORIES OF BOTH *Time* and *Newsweek* have featured global warming from the greenhouse effect and ozone depletion from industrial chemicals. The intense heat, forest fires, and drought of the summer of 1988 and the observation that the 1980s are the warmest decade on record have ignited an explosion of media, public, and governmental concern that the long debated global warming has arrived—and prompted some urgent calls for actions to deal with it. For example, the National Energy Policy Act of 1988 to control carbon dioxide emissions was introduced by Senator Wirth in August 1988, and hearings were held on 11 August. At that hearing, there were sharply conflicting views about whether policy actions are premature given the many remaining scientific uncertainties (*1, 1a*). Whether some amount of scientific uncertainty is "enough" to justify action or delay it is not a scientific judgment testable by any standard scientific method. Rather, it is a personal value choice that depends upon whether one fears more investing present resources as a hedge against potential future change or, alternatively, fears rapid future change descending without some attempt to slow it down or work actively to make adaptation to that change easier. That value choice can only be made efficiently by a society in which those involved in the decision-making process are aware of the nature of the scientific evidence. The public and governmental officials need to know which uncertainties are reducible, which may not be reducible, and how long it might take to narrow the reducible uncertainties. Uncertainties easily reducible in a few years might encourage waiting before implementing policy whereas uncertainties that are unreducible or difficult to reduce might suggest acting sooner. Of course, in the short term new research results may temporarily increase uncertainty, but with major efforts such as the proposed Global Change program, accelerated progress will be more likely (*2*). Therefore, in this article I discuss briefly many of the scientific questions surrounding the greenhouse effect debate. At the end I will turn to the issue of plausible responses.

The greenhouse effect, despite all the controversy that surrounds the term, is actually one of the most well-established theories in atmospheric science. For example, with its dense CO_2 atmosphere, Venus has temperatures near 700 K at its surface. Mars, with its very thin CO_2 atmosphere, has temperatures of only 220 K. The primary explanation of the current Venus "runaway greenhouse" and the frigid Martian surface has long been quite clear and straightforward: the greenhouse effect (*3*). The greenhouse effect works because some gases and particles in an atmosphere preferentially allow sunlight to filter through to the surface of the planet relative to the amount of radiant infrared energy that the atmosphere allows to escape back up to space. The greater the concentration of "greenhouse" material in the atmosphere (Fig. 1) (*4*), the less infrared energy that can escape. Therefore, increasing the amount of greenhouse gases increases the planet's surface temperature by increasing the amount of heat that is trapped in the lowest part of the atmosphere. What is controversial about the greenhouse effect is exactly how much Earth's surface temperature will rise given a certain increase in a trace greenhouse gas such as CO_2.

Two reconstructions of Earth's surface temperature for the past century (Fig. 2) have been made at the Goddard Institute for Space Studies (GISS) and Climatic Research Unit (CRU). Although some identical instrumental records were used in each study, the methods of analysis were different. Moreover, the CRU results include an ocean data set (*6*). These records have been criticized because a number of the thermometers were in city centers and might have measured a spurious warming from the urban heat island (*7*). In other cases thermometers were moved from cities to airports or up and down mountains, and some other measurements are also unreliable. A critical evaluation of the urban heat island effect suggests that in the United States the data may account for nearly 0.4°C of warming in the GISS record and about 0.15°C warming in the CRU record (*8*). Because the U.S. data from where the urban

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The author is at the National Center for Atmospheric Research, P.O. Box 3000, Boulder, CO 80307.

heat island effect might be significant are only a small part of the total, these corrections should not automatically be made to the entire global record. However, even after such corrections for the United States are applied to all of the data, the global data still suggest that 0.5°C warming occurred during the past 100 years. Moreover, the 1980s appear to be the warmest decade on record; 1981, 1987, and 1988 were the warmest years on these records (*5*, *6*).

Scientific Issues Surrounding the Greenhouse Effect

It is helpful to break down the set of issues known as the greenhouse effect into a series of stages, each feeding into another, and then to consider how policy questions might be addressed in the context of these more technical stages.

Projecting emissions. Behavioral assumptions must be made in order to project future use of fossil fuels (or deforestation, because this too can impact the amount of CO_2 in the atmosphere—it accounts for about 20% of the recent total CO_2 injection of about 5.5×10^9 metric tons). The essence of this aspect then is social science. Projections must be made of human population, the per capita consumption of fossil fuel, deforestation rates, reforestation activities, and perhaps even countermeasures to deal with the extra CO_2 in the air. These projections depend on issues such as the likelihood that alternative energy systems or conservation measures will be available, their price, and their social acceptability. Furthermore, trade in fuel carbon (for example, a large-scale transfer from coal-rich to coal-poor nations) will depend not only on the energy requirements and the available alternatives but also on the economic health of the potential importing nations (*9*). This trade in turn will depend upon whether those nations have adequate capital resources to spend on energy rather than other precious strategic commodities—such as food or fertilizer as well as some other strategic materials such as weaponry. Total CO_2 emissions from energy systems, for example, can be expressed by a formula termed "the population multiplier" by Ehrlich and Holdren (*10*)

$$\text{Total } CO_2 \text{ emission} = \frac{CO_2 \text{ emission}}{\text{technology}} \times \frac{\text{technology}}{\text{capita}} \times \text{total population size}$$

The first term represents engineering effects, the second standard of living, and the third demography in this version, which is expanded from the original.

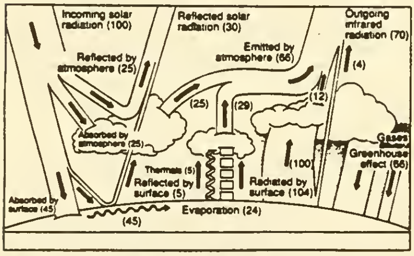
Incoming solar radiation (100)
Reflected solar radiation (30)
Outgoing infrared radiation (70)
Reflected by atmosphere (25)
Emitted by atmosphere (66)
(4)
(12)
(25)
(29)
Absorbed by atmosphere (25)
Gases
Greenhouse effect (66)
(100)
Thermals (5)
Reflected by surface (5)
Radiated by surface (104)
Absorbed by surface (45)
Evaporation (24)
(45)

Fig. 1. The greenhouse effect arises because Earth's atmosphere tends to trap heat near the surface. Water vapor, CO_2, and other trace greenhouse gases are relatively transparent to the visible and near-infrared wavelengths that carry most of the energy of sunlight, but they absorb more efficiently the longer, infrared (IR) wavelengths emitted by Earth. Hence an increase in the concentration of greenhouse gases tends to warm the surface by downward reradiation of IR, as shown. (The numbers are given in terms of the percentage each arrow represents relative to Earth-averaged solar constant, about 340 W/m².) [Modified from (*4*)]

Table 1. Vulnerability to climate change of water-resource regions of the United States. An asterisk indicates a region is vulnerable to indicated problem [from (*49*)]. Column 2 gives the number of thresholds exceeded in a region, those that are vulnerable to the most problems are listed first.

Basin	Number of thresholds	Vulnerability Category				
		Consumption	Storage	Variability	Hydroelectric	Ground water
Great Basin	5	•	•	•	•	•
Missouri	4	•		•	•	•
California	4	•	•	•	•	
Arkansas-White-Red	3		•	•		•
Texas-Gulf	3	•		•		•
Rio Grande	3	•		•		•
Lower Colorado	3	•			•	•
Tennessee	2		•		•	
Lower Mississippi	2		•	•		
Upper Colorado	2	•		•		
Pacific Northwest	2		•		•	
Alaska	2		•		•	
Caribbean	2		•	•		
New England	1		•			
Mid-Atlantic	1		•			
South Atlantic-Gulf	1		•			
Great Lakes	1		•			
Ohio	1		•			
Upper Mississippi	1		•			
Souris-Red-Rainy	1			•		
Hawaii	1		•			

In order to quantify future changes we can make scenarios (such as seen on Fig. 3) that show alternative CO_2 futures based on assumed rates of growth in the use of fossil fuels (*11*). Most typical projections are in the 0.5 to 2% annual growth range for fossil use and imply that CO_2 concentrations will double (to 600 ppm) the 21st century (*12*, *12a*). There is virtually no dispute among scientists that the CO_2 concentration in the atmosphere has already increased by ~25% since ~1850. The record at Mauna Loa observatory shows that concentrations have increased from about 310 to more than 350 ppm since 1958. Superimposed on this trend is a large annual cycle in which CO_2 reaches a maximum in the spring of each year in the Northern Hemisphere and a minimum in the fall. The fall minimum is generally thought to result from growth of the seasonal biosphere in the Northern Hemisphere summer whereby photosynthesis increases faster than respiration and atmospheric CO_2 levels are reduced. After September, the reverse occurs and respiration proceeds at a faster rate than photosynthesis and CO_2 levels increase (*13*). Analyses of trapped air in several ice cores (*14*) suggest that during the past several thousand years of the present interglacial, CO_2 levels have been reasonably close to the preindustrial value of 280 ppm. However, since about 1850, CO_2 has risen ~25%. At the maximum of the last Ice Age 18,000 years ago, CO_2 levels were roughly 25% lower than preindustrial values. The data also reveal a close correspondence between the inferred temperature at Antarctica and the measured CO_2 concentration from gas bubbles trapped in ancient ice (*15*). However, whether the CO_2 level was a response to or caused the temperature changes is debated: CO_2 may have simply served as an amplifier or positive feedback mechanism for climate change—that is, less CO_2, colder temperatures. This uncertainty arises because the specific biogeophysical mechanisms that cause CO_2 to change in step with the climate are not yet elucidated (*16*). Methane concent tions in bubbles in ice cores also show a similar close relation wit climate during the past 150,000 years (*17*).

Other greenhouse gases like chlorofluorocarbons (CFCs), CH_4, nitrogen oxides, tropospheric ozone, and others could, together, be as important as CO_2 in augmenting the greenhouse effect, but some of these depend on human behavior and have complicated biogeochemical interactions. These complications account for the large error bars in Fig. 4 (*18*). Space does not permit a proper treatment of individual aspects of each non-CO_2 trace greenhouse gas; therefore I reluctantly will consider all greenhouse gases taken together as "equivalent CO_2." However, this assumption implies that projections for "CO_2" alone (Fig. 3) will be an underestimate of the total greenhouse gas buildup by roughly a factor of 2. Furthermore, this assumption forces us to ignore possible relations between CH_4 and water vapor in the stratosphere, for example, which might affect polar stratospheric clouds, which are believed to enhance photochemical destruction of ozone by chlorine atoms.

Projecting greenhouse gas concentrations. Once a plausible set of scenarios for how much CO_2 will be injected into the atmosphere is obtained the interacting biogeochemical processes that control the global distribution and stocks of the carbon need to be determined. Such processes involve the uptake of CO_2 by green plants (because CO_2 is the basis of photosynthesis, more CO_2 in the air means faster rates of photosynthesis), changes in the amount of forested area and vegetation type, and how CO_2 fertilization or climate change affects natural ecosystems on land and in the oceans (*19*). The transition from ice age to interglacial climates provides a concrete example of how large natural climatic change affected natural ecosystems in North America. This transition represented some 5°C global warming, with as much as 10° to 20°C warming locally near ice sheets. The boreal species now in Canada were hugging the rim of the great Laurentide glacier in the U.S. Northeast some 10,000 years ago, while now abundant hardwood species were restricted to small refuges largely in the South. The natural rate of forest movement that can be inferred is, to order of magnitude, some ~1 km per year, in response to temperature changes averaging ~1° to 2°C per thousand years (*20*). If climate were to change much more rapidly than this, then the forests would likely not be in equilibrium with the climate; that is, they could not keep up with the fast change and would go through a period of transient adjustment in which many hard-to-predict changes in species distribution, productivity, and CO_2 absorptive capacity would likely occur (*21*).

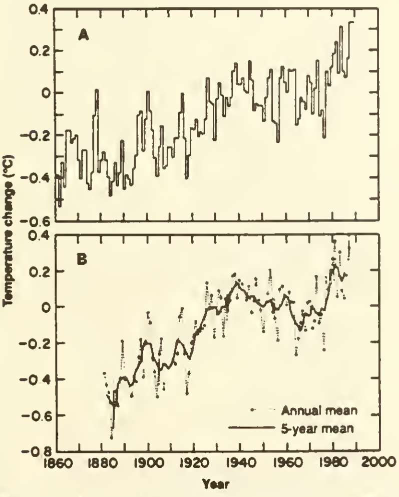

Fig. 2. A comparison of the global surface temperature trends of the past 100 years constructed from land and island stations and ocean surface temperature data sets at the (**A**) Climatic Research Unit and from a similar set of stations (minus the ocean surface temperature data set) at the (**B**) Goddard Institute for Space Studies [Modified from (*5, 6*)]

Furthermore, because the slow removal of CO_2 from the atmosphere is largely accomplished through biological and chemical processes in the oceans and decades to centuries are needed for equilibration after a large pertubation, the rates at which climate change modifies mixing processes in the ocean (and thus the CO_2 residence time) also needs to be taken into account. There is considerable uncertainty about how much newly injected CO_2 will remain in the air during the next century, but typical estimates put this so-called "airborne fraction" at about 50%. Reducing CO_2 emissions could initially provide a bonus by allowing the reduction of the airborne fraction, whereas increasing CO_2 emissions could increase the airborne fraction and exacerbate the greenhouse effect (*22*). However, this bonus might last only a decade or so, which is the time it takes for the upper mixed layer of the oceans to mix with deep ocean water. Biological feedbacks can also influence the amount of CO_2 in the air. For example, enhanced photosynthesis could reduce the buildup rate of CO_2 relative to that projected with carbon cycle models that do not include such an effect (*23*). On the other hand, although there is about as much carbon stored in the forests as there is in the atmosphere, there is about twice as much carbon stored in the soils in the form of dead organic matter. This carbon is slowly decomposed by soil microbes back to CO_2 and other gases. Because the rate of this decomposition depends on temperature, global warming from increased greenhouse gases could cause enhanced rates of microbial decomposition of necromass (dead organic matter) (*24*), thereby causing a positive feedback that would enhance CO_2 buildup. Furthermore, considerable methane is trapped below frozen sediments as clathrates in tundra and off

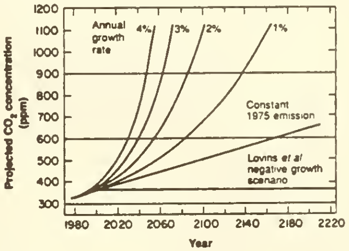

Fig. 3. The extent to which CO_2-induced climatic change will prove significant in the future depends, of course, on the rate of injection of CO_2 into the atmosphere. This depends, in turn, on behavioral assumptions as to how much fossil fuel burning will take place (biospheric effects are neglected in this graph). Since the end of World War II, a world energy growth rate of about 5.3% per year occurred until the mid-1970s, the time of the OPEC price hikes. Rates have come down substantially since then. The figure shows projected CO_2 concentrations for different annual growth rates in fossil energy use, including one for the assumption that no increase in fossil energy use occurs (constant 1975 emission) and even a "negative growth scenario" in which energy growth after 1985 is assumed to be reduced by a fixed amount [0.2 terra watts (TW) per year, which is about 2% of present demand] each year [Modified from (*11*)]

continental shelves. These clathrates could release vast quantities of methane into the atmosphere if substantial Arctic warming were to take place (*17, 25*). Already the ice core data have shown that not only has CO_2 tracked temperature closely for the past 150,000 years, but so has methane, and methane is a significant trace greenhouse gas which is some 20 to 30 times more effective per molecule at absorbing infrared radiation than CO_2. Despite these uncertainties, many workers have projected that CO_2 concentrations will reach 600 ppm sometime between 2030 and 2080 and that some of the other trace greenhouse gases will continue to rise at even faster rates.

Estimating global climatic response. Once we have projected how much CO_2 (and other trace greenhouse gases) may be in the air during the next century or so, we have to estimate its climatic effect. Complications arise because of interactive processes; that is, feedback mechanisms. For example, if added CO_2 were to cause a temperature increase on earth, the warming would likely decrease the regions of Earth covered by snow and ice and decrease the global albedo. The initial warming would thus create a darker planet that would absorb more energy, thereby creating a larger final warming (*26, 27*). This scenario is only one of a number of possible feedback mechanisms. Clouds can change in amount, height, or brightness, for example, substantially altering the climatic response to CO_2 (*28*). And because feedback processes interact in the climatic system, estimating global temperature increases accurately is difficult; projections' of the global equilibrium temperature response to an increase of CO_2 from 300 to 600 ppm have ranged from ~1.5° to 5.5°C. (In the next section the much larger uncertainties surrounding regional responses will be discussed.) Despite these uncertainties, there is virtually no debate that continued increases of CO_2 will cause global warming (*29–30*).

We cannot directly verify our quantitative predictions of greenhouse warming on the basis of purely historical events (*31*); therefore, we must base our estimates on natural analogs of large climatic changes and numerical climatic models because the complexity of the real world cannot be reproduced in laboratory models. In the mathematical models, the known basic physical laws are applied to the atmosphere, oceans, and ice sheets, and the equations that represent these laws are solved with the best computers available (*32*). Then, we simply change in the computer program the effective amount of greenhouse gases, repeat our calculation, and compare it to the "control" calculation for the present Earth. Many such global climatic models (GCMs) have been built during the past few decades, and the results are in rough agreement that if CO_2 were to double from 300 to 600 ppm, then Earth's surface temperature would eventually warm up somewhere between 1° and 5°C; the most recent GCM estimates are from 3.5° to 5.0°C (*27, 33*). For comparison, the global average surface temperature (land and ocean) during the Ice Age extreme 18,000 years ago was only about 5°C colder than that today. Thus, a global temperature change of 1° to 2°C can have considerable effects. A sustained global increase of more than 2°C above present would be unprecedented in the era of human civilization.

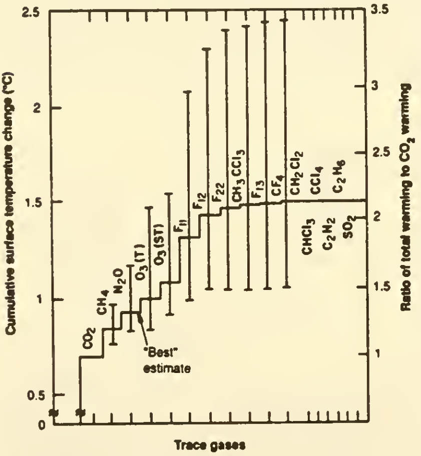

Fig. 4. Various trace "greenhouse gases" contribute about as much to equilibrium global warming (see right-hand scale) as CO_2 for the "best" estimate case, but uncertainties in the projected scenarios of these trace gases are large (see vertical bars). Additional uncertainties in equilibrium temperature response from climate model assumptions are not included in the figure. [Modified from (*18*)]

The largest uncertainty in estimating the sensitivity of Earth's surface temperature to a given increase in radiative forcing arises from the problem of parameterization. Because the equations that are believed to represent the flows of mass, momentum, and energy in the atmosphere, oceans, ice fields, and biosphere cannot be solved analytically with any known techniques, approximation techniques are used in which the equations are discretized with a finite grid that divides the region of interest into cells that are several hundred kilometers or more on a side. Clearly, critically important variables, such as clouds, which control the radiation budget of Earth, do not occur on scales as large as the grid of a general circulation model. Therefore, we seek to find a parametric representation or parameterization that relates implicitly the effects of important processes that operate at subgrid-scale but still have effects at the resolution of a typical general circulation model. For example, a parameter or proportionality coefficient might be used that describes the average cloudiness in grid cell in terms of the mean relative humidity in that cell and some other measures of atmospheric stability. Then, the important task becomes validating these semiempirical parameterizations because at some scale, all models, no matter how high resolution, must treat subgrid-scale processes through parameterization.

Projecting regional climatic response. In order to make useful estimates of the effects of climatic changes, we need to determine the regional distribution of climatic change. Will it be drier in Iowa in 2010, too hot in India, wetter in Africa, or more humid in New York; will California be prone to more forest fires or will Venice flood? Unfortunately, reliable prediction of the time sequence of local and regional responses of variables such as temperature and rainfall requires climatic models of greater complexity and expense than are currently available. Even though the models have been used to estimate the responses of these variables, the regional predictions from state-of-the-art models are not yet reliable.

Although there is considerable experience in examining regional changes [for example, Fig. 5 (*34*)], considerable uncertainty remains over the probability that these predicted regional features will occur. The principal reasons for the uncertainty are twofold: the crude treatment in climatic models of biological and hydrological processes (*35*) and the usual neglect of the effects of the deep oceans (*36*). The deep oceans would respond slowly—on time scales of many decades to centuries—to climatic warming at the surface, and also act differentially (that is, nonuniformly in space and through time). Therefore, the oceans, like the forests, would be out of equilibrium with the atmosphere if greenhouse gases increase as rapidly as typically is projected and if climatic warming were to occur as fast as 2° to 6°C during the next century. This typical projection, recall, is 10 to 60 times as fast as the natural average rate of temperature change that occurred from the end of the last Ice Age to the present warm period (that is, 2° to 6°C warming in a century from human activities compared to an average natural warming of 1° to 2°C per millennium from the waning of the Ice Age to the establishment of the present interglacial epoch) (*37*). If the oceans are out of equilibrium with the atmosphere, then specific regional forecasts like that of Fig. 5 will not have much credibility until fully coupled atmosphere-ocean models are tested and applied (*38*). The development of such models is a formidable scientific and computational task and is still not very advanced.

Validation of climatic model forecasts. Of course, it is appropriate to ask how climatic models' predictions of unprecedented climatic change beyond the next several decades might be verified. Can society make trillion dollar decisions about global economic developments based on the projections of these admittedly dirty crystal balls? How can models be verified?

The first verification method is checking the ability of a model to simulate today's climate. Reproduction of the seasonal cycle is one critical test because these natural temperature changes are several times larger, on a hemispheric average, than the change from an ice age to an interglacial period or a projected greenhouse warming. Also, "fast physics" such as cloud parameterizations can be tested by seasonal simulations or weather forecasts. Global climate models generally map the seasonal cycle well (Fig. 6) (*39*), which suggests that fast physics is not badly simulated on a global basis. However, successful reproduction of these seasonal patterns are not enough that strong validation can be claimed. Precipitation, relative humidity, and the other variables need to be checked. Reproduction of the change in daily variance of these variables with the seasons is another tough test (*40*). The seasonal tests, however, do not indicate how well a model simulates such medium or slow processes as changes in deep ocean circulation or ice cover, which may have an important effect on the decade to century time scales during which the CO_2 concentration is expected to double.

A second verification technique is isolating individual physical components of the model, such as its parameterizations, and testing them against high resolution submodels and actual data at high resolution. For example, one can check whether a parameterized evaporation matches the observed evaporation of a particular cell. But this technique cannot guarantee that the complex interactions of many individual model components are treated properly. The model may predict average cloudiness well but represent cloud feedback poorly. In this case, simulation of overall climatic response to increased CO_2 is likely to be inaccurate. A model should reproduce to better than, say, 25% accuracy the flow of thermal energy between the atmosphere, surface, and space (Fig. 1). Together, these energy flows comprise the well-established energy balance of Earth and constitute a formidable and necessary test for all models.

A third method for determining overall simulation skill is the model's ability to reproduce past climates or climates of other planets. Paleoclimatic simulations of the Mesozoic Era, glacial-interglacial cycles, or other extreme past climates help in understanding the coevolution of Earth's climate with living things. They are valuable for the estimation of both the climatic and biological future (*41*).

Overall validation of climatic models thus depends on constant appraisal and reappraisal of performance in the above categories. Also important are a model's response to such century-long forcings as the 25% increase in CO_2 concentration and different increases in other trace greenhouse gases since the Industrial Revolution.

Most recent climatic models predict that a warming of at least 1°C should have occurred during the past century. The precise "forecast" of the past 100 years also depends upon how the model accounts for such factors as changes in the solar constant or volcanic dust as well as trace greenhouse gases in addition to CO_2 (*42*). Indeed, the typical prediction of a 1°C warming is broadly consistent but somewhat larger than that observed (see Fig. 2). Possible explanations for the discrepancy include (*43*): (i) the state-of-the-art models are too sensitive to increases in trace greenhouse gases by a rough factor of 2; (ii) modelers have not properly accounted for such competitive external forcings as volcanic dust or changes in solar energy output; (iii) modelers have not accounted for other external forcings such as regional tropospheric aerosols from agricultural,

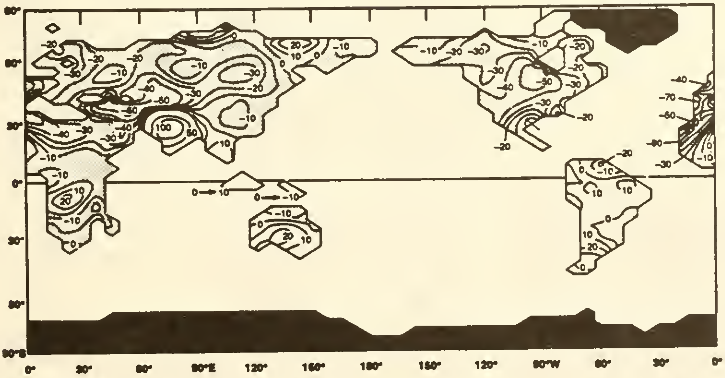

Fig. 5. CO_2-induced change in soil moisture expressed as a percentage of soil moisture obtained from a computer model with doubled CO_2 compared to a control run with normal CO_2 amounts. Note the nonuniform response of this ecologically important variable to the uniform change in CO_2. [Modified from (*34*)]

biological, and industrial activity; (iv) modelers have not properly accounted for internal processes that could lead to stochastic (*44*) or chaotic (*45*) behavior; (v) modelers have not properly accounted for the large heat capacity of the oceans taking up some of the heating of the greenhouse effect and delaying, but not ultimately reducing, warming of the lower atmosphere; (vi) both present models and observed climatic trends could be correct, but models are typically run for equivalent doubling of the CO_2 concentration whereas the world has only experienced a quarter of this increase and nonlinear processes have been properly modeled and produced a sensitivity appropriate for doubling but not for 25% increase; and (vii) the incomplete and inhomogeneous network of thermometers has underestimated actual global warming this century.

Despite this array of excuses why observed global temperature trends in the past century and those anticipated by most GCMs disagree somewhat, the twofold discrepancy between predicted and measured temperature changes is not large, but still of concern. This rough validation is reinforced by the good simulation by most climatic models of the seasonal cycle, diverse ancient paleoclimates, hot conditions on Venus, cold conditions on Mars (both well simulated), and the present distribution of climates on Earth. When taken together, these verifications provide strong circumstantial evidence that the current modeling of the sensitivity of global surface temperature to given increases in greenhouse gases over the next 50 years or so is probably valid within a rough factor of 2. Most climatologists do not yet proclaim that the observed temperature changes this century were caused beyond doubt by the greenhouse effect. The relation between the observed century-long trend and the predicted warming could still be chance occurrences, or other factors, such as solar constant variations or volcanic dust, may not have been accounted for correctly during the past century—except during the past decade when accurate measurements began to be made.

Another decade or two of observations of trends in Earth's climate, of course, should produce signal-to-noise ratios sufficier high that we will be able to determine conclusively the validity present estimates of climatic sensitivity to increasing trace greenhouse gases. That, however, is not a cost-free enterprise because a greater amount of change could occur then than if actions were undertaken now to slow down the buildup rate of greenhouse gases.

Scenarios of the environmental impact of CO_2. Given a set of scenarios for regional climatic change we must next estimate the impacts on the environment and society (*46, 47*). Most researchers have focused on the direct effects of CO_2 increases or used model-predicted maps of temperature and rainfall patterns to estimate impacts on crop yields or water supplies (*29a, 30, 48, 49*). Also of concern is the potential that temperature increases will alter the range or numbers of pests that affect plants, or diseases that threaten animals or human health (*50, 50a*). Also of interest are the effects on unmanaged ecosystems, principally forests. For example, ecologists are concerned that the destruction rate of tropical forests attributed to human expansion is eroding the genetic diversity of the planet (*51*). That is, because the tropical forests are in a sense major banks for the bulk of living genetic materials on Earth, the world is losing some of its irreplaceable biological resources through rapid development. Substantial changes in tropical rainfall have been predicted on the basis of climatic models; reserves (or refugia) that are currently set aside as minimal solutions for the preservation of some genetic resources into

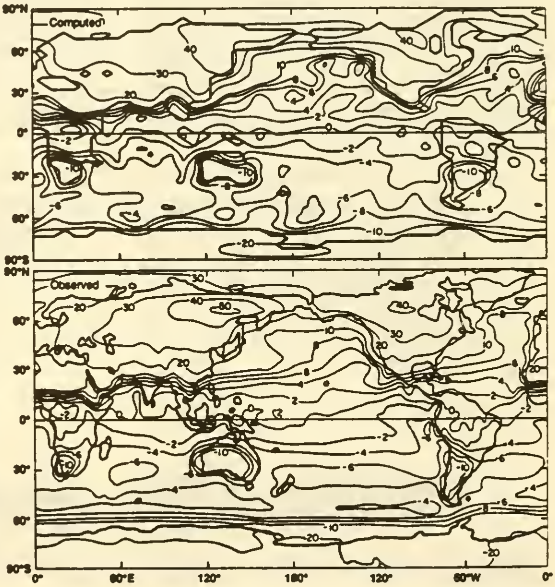

Fig. 6. A three-dimensional climate model has been used to compute the winter to summer temperature extremes all over the globe. The model's performance can be verified against the observed data shown below. This verification exercise shows that the model quite impressively reproduces many of the features of the seasonal cycle. These seasonal temperature differences are mostly larger than those occurring between ice ages and interglacials or for any plausible future carbon dioxide change. Although this approach cannot validate models for processes occurring on medium to long time scales (greater than 1 year), they are very encouraging for validating to a rough factor of 2 such "fast physics" paramaterizations like clouds. [Modified from (*39*)]

the future may not even be as effective as currently planned (*52*).

Climate changes resulting from greenhouse gas increases could also significantly affect water supply and demand. For example, a local increase in temperature of several degrees Celsius could decrease runoff in the Colorado River Basin by tens of percent (*25, 48*). A study (*53*) of the vulnerability to climate change of various water resource regions in the United States showed that some regions are quite vulnerable to climatic changes (Table 1).

Water quality will be diminished if the same volume of wastes are discharged through decreased stream flow. In addition, irrigation demand (and thus pressure on ground-water supplies) may increase substantially if temperatures increase without concomitant offsetting increases in precipitation. A number of climate models suggest that temperatures could increase and precipitation decrease simultaneously in several areas, including the central plains of the United States. Peterson and Keller (*54*) estimated the effects of a 3°C warming and a 10% precipitation change on U.S. crop production based on crop water needs. The greatest impact would be in the western states and the Great Plains, less in the Northwest. The warm, dry combination would increase depletion of streams and reduce viable acreage by nearly a third in the arid regions. New supplies of water would be needed, threatening ground water and the viability of agriculture in these regions. On the other hand, farmers in the East, and particularly in the Southeast, might profit if the depletion of eastern rivers were relatively less severe than that in the West or the Plains. However, increases in the efficiency of irrigation management and technological improvements remain achievable, and would help substantially to mitigate potential negative effects. Drying in the West could also markedly increase the incidence of wildfires, which in turn could act as agents of ecological change as climate changes.

Most workers project that an increase in global temperature of several degrees Celsius will cause sea level to rise by 0.5 to 1.5 m generally in the next 50 to 100 years (*55*); such a rise would endanger coastal settlements, estuarine ecosystems, and the quality of coastal fresh water resources (*56, 57*).

Economic, social, and political impacts. The estimation of the distribution of economic "winners and losers," given a scenario of climatic change, involves more than simply looking at the total dollars lost and gained—were it possible somehow to make such a calculation credibly! It also requires looking at these important equity questions: "who wins and who loses?" and "how might the losers be compensated and the winners charged?" For example, if the Cornbelt in the United States were to "move" north and east by several hundred kilometers from a warming, then a billion dollars a year lost in Iowa farms could well eventually become Minnesota's billion dollar gain. Although some macro-economists viewing this hypothetical problem from the perspective of the United States as a whole might see no net losses here, considerable social consternation could be generated by such a shift in climatic resources, particularly since the cause was economic activities (that is CO_2 production) that directed differential costs and benefits to various groups. Moreover, even the perception that the economic activities of one nation could create climatic changes that would be detrimental to another has the potential for disrupting international relations—as is already occurring in the case of acid rain. In essence, what greenhouse gas-induced environmental changes create is an issue of "redistributive justice."

If a soil moisture decrease, such as projected for the United States in Fig. 5 were to occur, then it would have disturbing implications for agriculture in the U.S and Canadian plains. Clearly, present farming practices and cropping patterns would have to change. The more rapidly the climate changed and the less accurately the changes were predicted (which go together), the more likely that the net changes would be detrimental. It has been suggested that a future with soil moisture change like that shown in Fig. 5 could translate to a loss of comparative advantage of U.S. agricultural products on the world market (*58*). Such a scenario could have substantial economic and security implications. Taken together, projected climate changes into the next century could have major impacts on water resources, sea level, agriculture, forests, biological diversity, air quality, human health, urban infrastructure, and electricity demand (*29a, 30, 47, 50, 57, 59*).

Policy responses. The last stage in diagnosing the greenhouse effect concerns the question of appropriate policy responses. Three classes of actions could be considered. First, engineering countermeasures: purposeful interventions in the environment to minimize the potential effects [for example, deliberately spreading dust in the stratosphere to reflect some extra sunlight to cool the climate as a countermeasure to the inadvertent CO_2 warming (*60*)]. These countermeasures suffer from the immediate and obvious flaw that if there is admitted uncertainty associated with predicting the unintentional consequences of human activities, then likewise substantial uncertainty surrounds any deliberate climatic modification. Thus, it is quite possible that the unintentional change might be overestimated by computer models and the intentional change underestimated, in which case human intervention would be a "cure worse than the disease" (*61*). Furthermore, the prospect for international tensions resulting from any deliberate environmental modifications is staggering, and our legal instruments to deal with these tensions is immature (*62*). Thus, acceptance of any substantial climate countermeasure strategies for the foreseeable future is hard to imagine, particularly because there are other more viable alternatives.

The second class of policy action, one that tends to be favored by many economists, is adaptation (*63*). Adaptive strategists propose to let society adjust to environmental changes. In extreme form, some believe in adaptation without attempting to mitigate or to prevent the changes in advance. Such a strategy is based partly on the argument that society will be able to replace much of its infrastructure before major climatic changes materialize, and that because of the large uncertainties, we are better off waiting to see what will happen before making potentially unnecessary investments. However, it appears quite likely that we are already committed to some climatic change based on emissions to date, and therefore some anticipatory steps to make adaptation easier certainly seems prudent (*64*). We could adapt to climate change, for example, by planting alternative crop strains that would be more widely adapted to a whole range of plausible climatic futures. Of course, if we do not know what is coming or we have not developed or tested the seeds yet, we may well suffer substantial losses during the transition to the new climate. But such adaptations are often recommended because of the uncertain nature of the specific redistributive character of future climatic change and because of high discount rates (*65*).

In the case of water supply management, the American Association for the Advancement of Science panel on Climate Change made a strong, potentially controversial, but, I believe, rather obvious adaptive suggestion: governments at all levels should reevaluate the legal, technical, and economic components of water supply management to account for the likelihood of climate change, stressing efficient techniques for water use, and new management practices to increase the flexibility of water systems and recognizing the need to reconsider existing compacts, ownership, and other legal baggage associated with the present water system. In light of rapid climate change, we need to reexamine the balance between private rights and the public good, because water is intimately connected with both. Regional transfers from water-abundant regions to water-deficient regions are often prohibited by legal or economic impediments that need to be examined as part of a hedging strategy for adapting more effectively to the prospect of climatic change even though regional details cannot now be reliably forecast (*66*).

Finally, the most active policy category is prevention, which could take the form of sulfur scrubbers in the case of acid rain, abandonment of the use of chlorofluorocarbons and other potential ozone-reducing gases (particularly those that also enhance global warming), reduction in the amount of fossil fuel used around the world or fossil fuel switching from more CO_2- and SO_2-producing coal to cleaner, less polluting methane fuels. Prevention policies, often advocated by environmentalists, are controversial because they involve, in some cases, substantial immediate investments as insurance against the possibility of large future environmental change, change whose details cannot be predicted precisely. The sorts of preventive policies that could be considered are increasing the efficiency of energy production and end use, the development of alternative energy systems that are not fossil fuel–based, or, in a far-reaching proposal: a "law of the air" proposed by Kellogg and Mead (*67*). They suggest that various nations would be assigned polluting rights to keep CO_2 emissions below some agreed global standard. A "Law of the Atmosphere" was recently endorsed in the report of a major international meeting (*68*).

A Scientific Consensus?

In summary, a substantial warming of the climate through the augmentation to the greenhouse effect is very likely if current technological, economic, and demographic trends continue. Rapid climatic changes will cause both ecological and physical systems to go out of equilibrium—a transient condition that makes detailed predictions tenuous. The faster the changes take place, the less societies or natural ecosystems will be able to adapt to them without potentially serious disruptions. Both the rate and magnitude of typical projections up to 2050 suggest that climatic changes beyond that experienced by civilization could occur. The faster the climate is forced to change, the more likely there will be unexpected surprises lurking (*69*). The consensus about the likelihood of future global change weakens over detailed assessments of the precise timing and geographic distribution of potential effects and crumbles over the value question of whether present information is sufficient to generate a societal response stronger than more scientific research on the problems—appropriate (but self-serving) advice which we scientists, myself included, somehow always manage to recommend (*70*).

High Leverage Actions to Cope with Global Warming

Clearly, society does not have the resources to hedge against all possible negative future outcomes. Is there, then, some simple principle that can help us choose which actions to spend our resources on? One guideline is called the "tie-in strategy" (*71*, *72*). Quite simply, society should pursue those actions that provide widely agreed societal benefits even if the predicted change does not materialize. For instance, one of the principal ways to slow down the rate at which the greenhouse effect will be enhanced is to invest in more efficient use and production of energy. More efficiency, therefore, would reduce the growing disequilibrium among physical, biological, and social systems and could buy time both to study the detailed implications of the greenhouse effect further and ensure an easier adaptation. However, if the greenhouse effects now projected prove to be substantial overestimates, what would be wasted by an energy efficiency strategy? Efficiency usually makes good economic sense (although the rate of investment in efficiency does depend, of course, on other competing uses of those financial resources and on the discount rate used). However, reductions in emissions of fossil fuels, especially coal, will certainly reduce acid rain, limit negative health effects in crowded areas from air pollution, and lower dependence on foreign sources of fuel, especially oil. In addition, more energy efficient factories mean reduced e v costs for manufacturing and thus greater long-term product cc itiveness against foreign producers (*11*, *12a*).

Development of alternative, environmentally safer energy technologies is another example of a tie-in strategy, as is the development and testing of alternative crop strains, trading agreements with nations for food or other climatically dependent strategic commodities, and so forth. However, there would be in some circles ideological opposition to such strategies on the grounds that these activities should be pursued by individual investment decisions through a market economy, not by collective action using tax revenues or other incentives. In rebuttal, a market which does not include the costs of environmental disruptions can hardly be considered a truly free market. Furthermore, strategic investments are made routinely on noneconomic (that is, cost-benefit analyses are secondary) criteria even by the most politically conservative people: to purchase military security. A strategic consciousness, not an economic calculus, dictates investments in defense. Similarly, people purchase insurance as a hedge against plausible, but uncertain, future problems. The judgment here is whether strategic consciousness, widely accepted across the political spectrum, needs to be extended to other potential threats to security, including a substantially altered environment occurring on a global scale at unprecedented rates. Then, the next problem is to determine how many resources to allocate.

If we choose to wait for more scientific certainty over details before preventive actions are initiated, then this is done at the risk of our having to adapt to a larger, faster occurring dose of greenhouse gases than if actions were initiated today. In my value system, leverage, tie-in actions are long overdue. Of course, whether tc not a scientific judgment, but a value-laden political choice that cannot be resolved by scientific methods.

Incentives for investments to improve energy efficiency, to develop less polluting alternatives, control methane emissions, or phase out CFCs may require policies that charge user fees on activities in proportion to the amount of pollution each generates. This strategy might differentially impact less developed nations, or segments of the population such as coal miners or the poor. Indeed, an equity problem is raised through such strategies. However, is it more appropriate to subsidize poverty, for example, through artificially lower prices of energy which distort the market and discourage efficient energy end use or alternative production, or is it better to fight poverty by direct economic aid? Perhaps targeting some fraction of an energy tax to help those immediately disadvantaged would improve the political tractability of any attempt to internalize the external costs of pollution not currently charged to energy production or end use. In any case, consideration of these political issues will be essential if global scale agreements are to be negotiated, and without global scale agreements, no nation acting alone can reduce global warming by more than 10% or so (*73*).

The bottom line of the implications of atmospheric change is that we are perturbing the environment at a faster rate than we can understand or predict the consequences. In 1957, Revelle and Suess (*74*) pointed out that we were undergoing a great "geophysical experiment." In the 30 years since that prophetic remark, CO_2 levels have risen more than 10% in the atmosphere, and there have been even larger increases in the concentrations of methane and C The 1980s appear to have seen the warmest temperatures i instrumental record, and 1988 saw a combination of dramatic circumstances that gained much media attention: extended heat waves across most of the United States, intense drought, forest fires in the West, an extremely intense hurricane, and flooding in Bangladesh. Indeed, many people interpreted (prematurely, I believe) these events in 1988 as proof that human augmentation to the greenhouse effect had finally arrived (*75*). Should the rapid warming in the instrumental record of the past 10 years continue into the 1990s, then a vast majority of atmospheric scientists will undoubtedly agree that the greenhouse signal has been felt. Unfortunately, if society chooses to wait another decade or more for certain proof, then this behavior raises the risk that we will have to adapt to a larger amount of climate change than if actions to slow down the buildup of greenhouse gases were pursued more vigorously today. At a minimum, we can enhance our interdisciplinary research efforts to reduce uncertainties in physical, biological, and social scientific areas (*76*). But I believe enough is known already to go beyond research and begin to implement policies to enhance adaptation and to slow down the rapid buildup of greenhouse gases, a buildup that poses a considerable probability of unprecedented global-scale climatic change within our lifetimes.

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48. H. E. Schwarz and L. A. Dillard, in (*48a*).

48a. P. E. Waggoner, Ed., *Climate Change and U.S. Water Resources* (Wiley, New York, in press).

49. *Climate, Climatic Change, and Water Supply*, Studies in Geophysics (National Academy of Sciences, Washington, DC, 1977); M. P. Farrell, Ed., *Master Index for the Carbon Dioxide Research State-of-the-Art Report Series*, (U.S. Department of Energy, Washington, DC, 1987); J. J. Hanchey, K. E. Schilling, E. Z. Stakhiv, in *Preparing for Climate Change, Proceedings of the First North American Conference on Preparing for Climate Change: A Cooperative Approach*, Washington, DC, 27 to 29 October 1988 (Government Institutes, Rockville, MD, 1988), pp. 394–405; M. L. Parry, Ed., *Climatic Change* 7, 1 (1985).
50. W. H. Weihe, in Proceedings of the World Climate Conference (World Meteorological Organization, Geneva, 1979).

50a. A. Dobson, in *Proceedings of Conference on the Consequences of the Effect for Biological Diversity*, R. Peters, Ed. (Yale Univ. Press, New Haven, in press).

51. N. Myers, *The Sinking Ark* (Pergamon, New York, 1979); see also J. Gradwohl and R. Greenberg, *Saving the Tropical Forests* (Island Press, Washington, DC, 1988)
52. R. H. MacArthur and E. O. Wilson, *The Theory of Island Biogeography* (Princeton Univ. Press, Princeton, NJ, 1967); R. L. Peters and J. D. Darling, *Bioscience* 35, 707 (1985); T. E. Lovejoy, in *The Global 2000 Report to the President: Entering the 21st Century*, Council on the Environmental Quality and the Department of State (U.S. Government Printing Offices, Washington, DC, 1980, p. 328–331).
53. P. H. Gleick, in (*48a*).
54. D. F. Peterson and A. A. Keller, in (*48a*).
55. G. de Q. Robin in (*30*); M. F. Meier *et al.*, *Glaciers, Ice Sheets, and Sea Level* (National Academy of Sciences, Washington, DC, 1985). Sea level rises greater than 1.5 m and less than 0.5 m, perhaps even sea level falls, could also occur in the next 50 to 100 years, although most analysts give these extremes low probabilities. Should a much more rapid disintegration of the West Antarctic Ice Sheet than now envisioned occur, sea levels would rise substantially because this glacier has above-ground ice sufficient to raise sea level by ~5 m. On the other hand, because a warming of Antarctica would almost certainly increase snowfall without raising temperatures sufficiently to create summer melt, a doubling of the snowfall over Antarctica could lower sea level perhaps as much as 1 mm per year. Of course, such a change would require that the calving rate in Antarctica does not increase. The same would have to apply for the melting and calving in Greenland, an ice sheet which, unlike Antarctica, has substantial melting at lower altitudes and low-latitude flanks. However, the principal factor responsible for the "most probable" estimate of 0.5- to 1.5-m sea level rise is the assumption that some mountain glaciers will disappear while, at the same time, several degrees Celsius warming of the oceans will, through the direct process of thermal expansion (which is several times greater in warm water than cold water), lead to an inexorable increase in ocean volume and rise of the sea level. A rise of sea level seems highly probable, whereas disintegration of the West Antarctic Ice Sheet or snow accumulation in each Antarctica are much more speculative, and such changes will in any case, occur more slowly in response to climate change. Sea level rise only exacerbates the likelihood of catastrophic storm surges especially if warming increases hurricane intensity; K. A. Emanuel, *Nature* 326, 483 (1987).
56. G. P. Hekstra, in *Proceedings of Controlling and Adapting to Greenhouse Warming* (Resources for the Future, Washington, DC, in press); M. C. Barth and J. G. Titus, Eds., *Greenhouse Effect and Sea Level Rise: A Challenge for this Generation* (Van Nostrand, Reinhold, New York, 1984). The Environmental Protection A (EPA), in a comprehensive study of potential scenarios of climate change f United States (*57*), concluded that building of bulkheads and levies, pumping and raising barrier islands to protect areas against a 1-m rise in sea level by 2100 would cost $73 billion to $100 billion (cumulative capital costs in 1985 dollars). In contrast, elevating beaches, houses, land, and roadways by the year 2100 would cost $50 billion to $75 billion (cumulative capital costs in 1985 dollars) [(*57*), chap. 9].
57. J. B. Smith and D. Tirpak, Eds., *The Potential Effects of a Global Climate Change on the United States*, Draft Report to Congress (Environmental Protection Agency, Washington, DC, October 1988) vol. 2, chap. 9.
58. M. Parry, W. Easterling, P. Crosson, N. Rosenberg, *Resources for the Future Conference Proceedings*, in press; The scenario with the Geophysical Fluid Dynamics Laboratory computer model for soil drying is more severe in central North America than that for other models, such as the Goddard Institute for Space Studies. The agricultural consequences of a number of model scenarios including hypothetical increases in yield resulting from direct CO_2 fertilization and decreases due to heat stress or drought stress are assessed in (*57*). Although no general rules for any crop or region could be determined from the EPA analysis (chap. 10), crop yield changes from a few tens of percent advantages to 50% reductions were obtained. At a minimum, one robust conclusion could be drawn: climate changes of the magnitudes projected in most GCM results for the middle to the late part of the next century certainly will cause major redistribution of cropping zones and farming practices.
59. R. S. Chen, E. M. Boulding, S. H. Schneider, Eds., *Social Science Research and Climate Change: An Interdisciplinary Appraisal* (Reidel, Dordrecht, Netherlands, 1983); The Environmental Protection Agency report (*57*) is the most comprehensive analysis of potential impacts and adaptive strategies and costs, although it was restricted to the United States, and at that, only half a dozen or so regions.
60. M. I. Budyko, *Climatic Changes* (Hydrometeorological Publishers, Leningrad, 1974) (in Russian); C. Marchetti, *Climatic Change* 1, 59 (1977).
61. S. H. Schneider and L. E. Mesirow, *The Genesis Strategy: Climate and Global Survival* (Plenum, New York, 1976), chap. 7, p. 215.
62. W. W. Kellogg and S. H. Schneider, *Science* 186, 1163 (1974).
63. K. Meyer-Abich, *Climatic Change* 2, 373 (1980); L. B. Lave, *International Institute for Applied Systems Analysis, IIASA Rep. CP-81-14* (1981), p. Vi, T. Schelling, in *Changing Climate, Report of the Carbon Dioxide Assessment Committee* (National Academy Press, Washington, DC 1983), p. 449.
64. S. H. Schneider and S. L. Thompson [in *The Global Possible: Resources, Devel and the New Century*, R. Repetto, Ed. (Yale Univ. Press, New Haven, 19 397] call this "anticipatory adaptation".
65. Much of the decision as to whether it is cost effective to wait or act against potential threats depends upon the discount rate used to value potential future losses. For example, S. H. Schneider and R. S. Chen [*Annu. Rev. Energy* 5, 107 (1980)] described how damage from a sea level rise of 8 m could cost about 1 trillion 1980 dollars some 150 years in the future. At a discount rate of 7% per year, which implies a doubling of an economic investment every 10 years, this hypothesized trillion dollar loss 150 years hence would only be "worth" some $33 million today, less than the value of a single power plant. Although an 8-m rise now seems a low probability, the discounting example remains instructive.
66. In the example of water supplies and climatic change, most of the local policy decisions facing urban water engineers or rural irrigation planners would be easiest to face if we had more credible specific regional forecasts of temperature and precipitation changes (*48*). However, regional details are the most difficult variables to predict credibly. Thus, strategies to build flexibility in adapting to changing climate statistics seem appropriate for local or regional water supply planning. Because of uncertainty over details, an individual planner in a region may face difficulty in choosing exactly how to respond to the advent or prospect of rapid climate change. But this should not necessarily deter strategic hedging at national or international levels. In other words, most local or regional water supply planners would not welcome the prospect of rapidly changing climate. Therefore, most planners would hold that if the rate of climate change could be slowed down and time bought to study the outcomes and to adapt more cheaply that this would be an appropriate recommended national-level strategic response.
67. W. W. Kellogg and M. Mead, *The Atmosphere: Endangered and Endangering* (U.S. Department of Health, Education and Welfare, Washington, DC, 1975)
68. Conference statement, *The Changing Atmosphere: Implications for Global Security*, Toronto, Ontario, Canada, 27 to 30 June 1988 (Environment Canada, Toronto, 1988). The report noted that the "first steps in developing international law and practices to address pollution of the air have already been taken." Several examples are cited in it, in particular the Vienna Convention for the Protection of the Ozone, Air, and Its Montreal Protocol signed in 1987. The report states that "These are important first steps and should be actively implemented and respected by all nations. However, there is no overall convention constituting a comprehensive international framework that could address the interrelated problems of the global atmosphere, or that is directed toward the issues of climate change." It set forth a far-reaching action plan that would have major implications for government, industry, and populations. This report follows on the heels of the United N Commission on Environment and Development, known as the Bruntland mission Report, which argued that environment, development, and security sh not be treated as separate issues, but rather as connected problems

69. W. S. Broecker, testimony for U.S. Senate Subcommittee on Environmental Protection, 28 January 1987.

70. It is important to ask how long it might take the scientific community to be able to provide more credible time-evolving regional climatic anomaly forecasts from increasing greenhouse gases, S. H. Schneider, P. H. Gleick, L. Mearns in (*49*), Schneider *et al* suggested that it will be at least 10 years and probably several decades before the current level of scientific effort can provide a widespread consensus on these details The reason such time is needed at current levels of effort is that providing credible regional details will require the coupling of high resolution atmosphere, ocean, and sea ice models with ecological models that provide accurate fluxes of energy and water between atmosphere and land as well as nutrient cycling and chemical transformations that account for trace greenhouse gas buildup over time. A dedicated effort to accelerate the rate of progress could conceivably speed up the establishment of a consensus on regional issues, but at best 10 years or so will be necessary even with a dramatic effort. However, such efforts would clearly put future decision making on a firmer factual basis and help to make adaptation strategies more effective sooner

71. The "tie-in" strategy was first formulated by E. Boulding, *et al* [in *Carbon Dioxide Effects, Research and Assessment Program Workshop on Environmental and Societal Consequences of a Possible* CO_2*-induced Climatic Change*, Report 009, CONF-7904143, U.S. Department of Energy (Government Printing Office, Washington, DC, October 1980), pp 79–103]; it was later adopted by W. W. Kellogg and R. Schware, *Climate Change and Society, Consequences of Increasing Atmospheric Carbon Dioxide* (Westview Press, Boulder, CO, 1981)

72. S. H. Schneider and S. L. Thompson, in *The Global Possible Resources, Development and the New Century*, R. Repetto, Ed., (Yale Univ. Press, New Haven, 1985), pp 397–430.

73 J A. Edmonds, W. B. Ashton, H. C. Cheng, and M Steinberg (in preparation) have calculated that the U.S contributes some 5% of CO_2 emissions, but this fraction could drop significantly if it holds emissions growth while other nations with large populations try to catch up with U.S per capita energy use standards

74. R. Revelle and H Suess, *Tellus* 9, 18 (1957).

75. K E. Trenberth, G. W Branstator, P A. Arkin, *Science* 242, 1640 (1988); S H Schneider, *Climatic Change* 13, 113 (1988). Clearly, one hot year can no more prove that the greenhouse effect has been detected in the record any more than a few cold ones could disprove it. The 1990s, should they see a continuation of the sharp warming trend of the 1980s, will undoubtedly lead many more scientists to predict confidently that the increase in trace greenhouse gases has caused direct and clearly detectable climatic change Already a few scientists are satisfied that the effects are 99% detectable in the record. J. Hansen (*1a*); see also, J. N Wilford *New York Times*, 23 August 1988, p. C4

76. *Toward an Understanding of Global Change, Initial Priorities for U.S Contributions to the International Geosphere-Biosphere Program* (National Academy Press, Washington, DC, 1988); S. H. Schneider, *Issues Sci. Technol* IV (no 3), 93 (1988).

77. I thank J. Ausubel, G. J. MacDonald and two anonymous reviewers for useful comments on the first draft. I also thank S Mikkelson for efficient word processing and correcting several drafts of the manuscript very quickly The National Center for Atmospheric Research is sponsored by the National Science Foundation Any opinions, findings, conclusions, or recommendations expressed in this article are those of the author and do not necessarily reflect the views of the National Science Foundation.

Mr. SHARP. Thank you very much.

I think we're ready now for Dr. Michaels, except I'm looking for where that projector is.

[Pause.]

Mr. SHARP. Dr. Michaels, we're ready.

STATEMENT OF PATRICK J. MICHAELS

Mr. MICHAELS. I'd like to thank you for inviting my commentary before the subcommittee.

This is a very strange projector, by the way, because it keeps on going forward when I walk by it. A magic projector.

I'm somewhat amused that I'm supposed to be the conservative person speaking to the committee. I'm thinking of Steve's graphic, an ultimate graphic. Perhaps I should start a club, "Conservatives Who Voted For Walter Mondale." I think I could be the president and the vice president and everybody else.

Another thing that interests me is the ostensible disagreement that is portrayed between the members of this committee. No one on this committee would dispute the fact that anthropogenerated climate changes—in fact, the most potential, in underlying potential the most serious environmental disturbance ever created by technological man.

My purpose in this discussion is to underscore, in fact, that our policy should be commensurate with the state of scientific knowledge.

Now I'm going to have to repeat something that everybody else repeated here. First, measurements of carbon dioxide from Hawaii in 1955 give a preindustrial concentration of about 315 parts per million in the late 1950's again. It was initially thought that they came up to about 295 parts per million, which would have given us a warming of about 0.7°C if the world were in equilibrium. That initially seemed consonant with the anthropogenerated changes.

Several findings since then indicate that the problem is much more complicated. These include exponential increases in other thermally active trace gases and new findings on the geographic distribution of warming and its distribution between night and day. Commentary on these will comprise the balance of my testimony.

Changes on trace gas concentrations. Antarctic ice core measurements now place the background CO_2 concentration between 260 and 280 parts per million. If we use the midpoint, the expected equilibrium warming would be 1.1°C. Other thermally active trace gases have also been increasing exponentially; in particular, methane, nitrogen oxides, and the chlorofluorocarbons.

Tom Wigley of the University of East Anglia calculates that the combined effect of these should be the equivalent of an additional effective increase of 57 parts per million. Thus if all the other radiatively active trace gases were expressed as if they were carbon dioxide, the current carbon dioxide concentration would be 407 parts per million or 151 percent of background. The fact is, radiatively we have gone over halfway to a doubling of carbon dioxide since the beginning of the Industrial Revolution.

Under equilibrium conditions, the Earth would have warmed 1.8°C from these trace gas disturbances. If the lower limit background of 260 parts per million is used, the expected mean warming is very close to 2°C. Now obviously that hasn't occurred, and there are good reasons why and good scientific reasons.

There is an unknown lag effect that occurs because of the oceans. However, Wigley has calculated that even the most liberal estimates of this lag imply an expected warming of 1°C. At best, the Earth appears to have warmed up only half as much as our average forecasts indicate it should have. A mathematical argument in Dr. Schneider's journal, Climatic Change, suggests that the oceans might mitigate expected surface warming by a factor of three.

Now I'd like to show a couple of slides.

The usual presentation is to show the global curve and to not break it into hemispheres or regions, and I'd like to show you something very interesting. The first slide here is the Southern Hemisphere. Most people who look at the Southern Hemisphere data will tell you that this looks an awful lot like what we would expect in greenhouse world, although the magnitude is not as great as we would think it should be at this point in time.

You do see what appears to be an exponential increase in the temperature and, in fact, it's going up quite rapidly by the time we get into the late 1970's.

Now when we look at the Northern Hemisphere, that's where the problem becomes much more complicated. If, in fact, oceanic thermal lag, this lag of the system, is holding back the warming, you would expect the ocean hemisphere would be the one that would warm last. That's the Southern Hemisphere. The Northern Hemisphere should be, in fact, first to go under that rather simple argument, and if you look at it, it doesn't show that signature.

If you take a look at the last 55 years in the Northern Hemisphere, I can't find a statistician even in this town that will tell me that there is a warmup in that data.

Now one of the interesting things here is, these last few years here in the 1980's—this chart, by the way, is a couple of years old—in fact, are warmer than the other years in the record. But the question is, how much warmer? They are not warm enough in the Northern Hemisphere, in fact, to establish a trend over that period.

Now I want to talk about another problem that I find really quite fascinating, and again, I'm not trying to say that this is not a problem. This is potentially a very serious environmental problem. The question is, what is the state of what we know, and what is the state of the future?

Tom Karl and others from NOAA provide an additional layer of complexity on this problem by looking at the change in temperature that has occurred over the United States in something called the historical climate network. The historical climate network is special. Tom Karl is a person to be commended for diligent and painstaking scientific work. What he has done is, he has taken the urban effect, the city effect, the population effect out of the U.S. data. The United States has a nice mix of urban and rural stations in which he can do that. And his analyses indicate that daily temperature ranges—that's the difference between the high and the low temperature—are declining since these additions of trace gases into the atmosphere, and I will show you this—let's see, I don't know how far this is going to stretch.

[Pause.]

Mr. MICHAELS. What we're interested in here is the graph on the lower right. This is the difference between mean daily high and mean daily low temperature across the United States. By the way, this is the graph for mean daily high temperature, which has declined, and the nighttime temperatures have either stayed the same or come up slightly with respect to the daytime temperatures.

That's a very interesting phenomenon because that, in fact, is a characteristic signature that one might think would occur in a greenhouse world. The implication is that the effect may be expressing itself primarily as a rise in the nighttime temperatures, while daytime temperatures have, in fact, declined. This could be caused by increased cloudiness, which has been noted in four reports in the scientific literature, or by the infrared-absorbing effect of the greenhouse gases. It is my opinion that it is likely a combination of the two, frankly.

The peculiarity of this—and this is where the problem gets very complicated—is that if such a trend continues—and that "if" is very large, okay; that's very dangerous in this business to say "if it continued"—the greenhouse world would be one in which the growing seasons were longer, because the nighttime temperatures increase. There would be more precipitation, perhaps less skin cancer because of increased cloudiness, and plants would grow better because of the well-known effect of carbon dioxide fertilization.

I don't necessarily believe that's the case, okay. However, this, I'll call it "positive vision" of the future climate was recently presented by the Soviet academician, Mikhail Budyko, in a paper first read at NOAA-sponsored meeting of the Climate Trends Panel last September. Budyko's position in the Soviet science establishment, incidentally, is analogous to being the highest echelons of our National Center for Atmospheric Research. I only bring this up to underscore the broad range of expert opinion that appears on this subject, not to say that, in fact, that is the way the future will be.

I will finish on the urbanization problem here, because I find that a very interesting thing that we have to deal with. This again is the work of Tom Karl. This will be published in the 1989 March issue of the "Bulletin of the American Meteorological Society." He's going to show—I think it's my next slide—nope; sorry about that. We'll skip that one. He's going to show that when you compare the historical climate network—that's the unurbanized set over the United States—to roughly the same area that is used in the NASA temperature record that has caused so much ferment in its presentations, that the NASA record warms up 0.4° compared to the unurbanized record. That's a lot, because the NASA record warms up about 0.7°C over the 20th century.

It is important to note that there is no a priori reason to suspect that this urban bias is appreciably different in other portions of the industrialized world. So a simple extension to the globe—and I'm going to tell you right now, I can't rigorously defend that extension because nobody has done it; it hasn't come up on the priority list yet. A simple extension would yield a residual warming of somewhere between 0.2°C and 0.3°C, an amount which is somewhere between 2 and 3 times less than that predicted by the climate models for this point in time.

The other popularly cited climate record, the East Anglia group's record which Steve referred to, leaves essentially the same residual when an analogous calculation is performed.

Now I think it would be extremely important to take a look at this from the computer modeling point of view, and several people have. Jim Hansen has run what he calls transient models of climate change, where he looks at areas the size of the United States, and he concludes, yes, they, in fact, could run cooler than the rest of the world for periods of decades. However, analogous studies of Canadian data and my own temperature calculations over Alaska show that the area of no significant temperature change for the last 50 years is virtually all of North America. It is doubtful this can be accommodated by a transient model over such a large area.

I think it would be important to extend these types of analyses that I've shown you to other regions with analogous urban and rural climate distributions, such as the Soviet Union. I urge that you give what would have to be a joint effort in this your highest priority. Many people working on this problem very much would like to cooperate with the Soviet Union on this.

In addition, I urge the support of other important investigations that will help us determine the Earth's true temperature history and find out, in fact, how the changes in trace gases will eventually be expressed.

Now please take my observations in the proper context. They are not intended to minimize the importance of the climatic change problem, but rather to emphasize its complexity. I personally find it risky to enact sweeping environmental policy based upon visions that are clouded and possibly even failing. Further, if the models that eventually were proved not to be as—if the warming were not as much as the models, in fact, indicated on the average, if this were used as a linchpin for an otherwise rational energy policy—and I believe that policies that people are thinking of are, in fact, rational and reasonable—you're going to get no one here to say that energy conservation is a bad idea; however, if those, in fact, those models get into trouble, the policy could suffer a serious loss in credibility, and I believe that would set back progress on those important policy issues for decades.

Thank you.

[The prepared statement of Dr. Michaels follows:]

Statement of Patrick J. Michaels to the Subcommittee on Energy and Power, U.S. House of Representatives, February 21, 1989:

I would like to thank the Subcommittee for inviting my commentary on the important topic of anthropogenerated climatic change.

As a matter of introduction, I note recent news and editorial stories stating that evidence is sufficiently compelling for the U.S. to now factor anthropogenerated global warming into the domestic and foreign policy matrix. The tenor of these pieces--and I have seen several--is that while there some areas of disagreement or inconsistencies in our current understanding, it is high time for sweeping proaction.

My purpose here is not to throw roadblocks in the way of sensible environmental policy. No one on this panel would contest the fact that anthropogenerated global climatic change is potentially the most serious environmental disturbance ever created by technological man. My purpose is rather to underscore that policy should be commensurate with the state of scientific knowledge.

It is doubtless that carbon dioxide, an effective absorber of infrared radiation, is increasing exponentially in the atmosphere as a result of man's activities. First measurements from Hawaii found concentrations of 315 parts million (ppm) in the late 1950's, while today's concentrations are nearly 350ppm. In the early 1980's, the "preindustrial" background concentration was estimated at 295ppm, giving an increase of 19% since the beginning of widespread thermometric records.

If the earth had come to immediate thermal equilibrium, that change could have produced a global warming of 0.7° C. Because measured warming was thought to be between 0.4° and 0.7° C, depending upon which record is used, the observed changes initially seemed consonant with anthropogenerated CO2 increases.

Several findings since then indicate the problem is much more complicated. These include the exponential increases in other thermally-active trace gases, new findings on the geographic distribution of warming and its division between night and day, and recent work on the effect of urban bias on regional temperatures. Commentary of these will comprise the balance of my testimony.

1. Changes in trace-gas concentrations.

Antarctic ice core measurements now place the background CO2 concentration between 260 and 280 ppm. If we use the midpoint, the expected equilibrium warming could be 1.1°C.

Other thermally active trace gases have also been increasing exponentially, in particular, methane, nitrogen oxides, and the chloroflourocarbons. Tom Wigley, of the University of East Anglia, calculates that the combined effect of these should be equivalent to an additional effective increase of 57ppm. Thus, if all of the other radiatively active gases were expressed as if they were CO2, the concentration of carbon dioxide would be

407ppm, or 151% of a background of 270ppm.

Under equilibrium conditions, the earth should have warmed 1.8 °C from these trace gas disturbances. If the lower limit background of 260ppm is used, the expected mean global warming is very close to two degrees Celsius. As noted above, measured warming has been between 0.4° and 0.7° C. As noted below, that warming itself is subject to some question.

2. The Spatial and Temporal Distribution of Observed Warming

There is an unknown lag effect that occurs because of the oceans. Wigley has calculated, however, that even the most liberal estimates of this lag imply an expected warming of 1.0° C (or 1.2° with the lower background CO2 of 260ppm). At best, the earth appears to have warmed up only half as much as our average forecasts indicate it should have. A mathematical argument in Dr. Schneider's Journal Climatic Change suggested the oceans might mitigate expected surface warming by a factor of three.

The oceanic lag argument is complicated by the differing behavior of the Earth's hemispheres. Southern Hemisphere temperatures, according to Jones and others at East Anglia, display a thermal signal that is much like we would expect in a Greenhouse World--little change through the 1940's, followed by an exponential increase, albeit one of approximately half the magnitude expected even with liberal thermal lag arguments.

Northern hemisphere temperatures show at least one-half of their increase before the major trace gas emissions. In fact, there is no statistically significant trend for the last 55 years. Hugh Elsaesser, of the Lawrence Laboratory, demonstrated that most of our hemisphere's warming can be ascribed to a period during Woodrow Wilson's presidency.

Most scientists directly involved with this research problem cite the hemispheric disparity as either counter to or beyond the current pale of our understanding.

3. The Diurnal Problem

Work by Tom Karl and others from NOAA provide an additional layer of complexity on the climate change problem.

Careful analyses of the unurbanized Historical Climate Network data indicate that daily temperature ranges over the United States are declining since the significant addition of trace gases. In particular, it appears that night minimum temperatures are rising relative to daytime maxima. The implication is that the greenhouse effect could be expressing itself primarly as a rise in the nighttime temperatures, while daytime temperatures have in fact declined.

This could be cause either by increased cloudiness, which has been noted in four reports in the refereed scientific literature, or by the infrared absorbing effects of anthrpogenerated trace gases. It is more likely that the reduction in daily range results from a combination of the two.

The pecularity is that if such a trend continued, greenhouse world could be one where growing seasons were longer (because nighttime temperatures increased), there was more precipitation and less skin cancer (because of increased cloudiness) and plants grew better (because of the well known effect of carbon dioxide fertilization).

The "positive" vision of future climate was recently presented by Soviet Academician Mikhail Budyko, in a paper first read at a NOAA sponored meeting of the Climate Trends Panel last September. Budyko's position in the Soviet science establishment is roughly analogous to being in the highest echelons of our National Center for Atmospheric Researach. I only bring it up to underscore the broad range of expert opinion that exists on this subject.

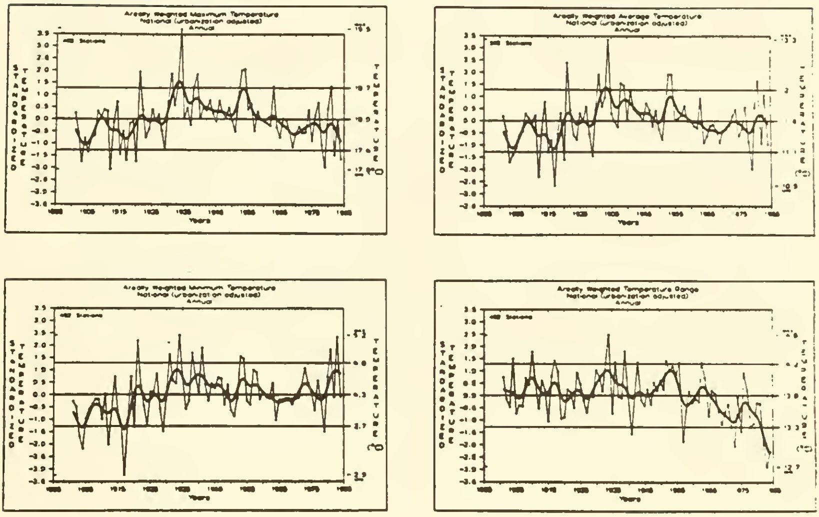
With regard to observed temperature changes, the current draft of the Climate Trends Panel meeting proceedings states that "the overall magnitude of the surface warming since the latter 19th century...is about half of that expected by most GCM simulations given the best estimate of changes in greenhouse gases over this period."

4. The Urbanization Problem.

It is well known that long term climate records sometimes warm because their surroundings become more urbanized, and while much has been written on this problem, it remains elusive. In the March, 1989, issue of the Bulletin of the American Meteorological Society, NOAA scientist Tom Karl will publish a paper that compares NASA climate records over the U.S. to the urbanization-adjusted Historical Climate Network. The paper will show that the published NASA record warms up 0.4° in the twentieth century compared to the unurbanized record. It is important to note that there is no *a priori* reason to suspect that the urban bias is appreciably different in other portions of the industrialized world. A simple extension to the globe--which is not possible to rigorously defend at this time because the exhaustive research has not been performed--would yield a residual warming of 0.2-0.3°, an amount which is three *times* less than that predicted by the average of our sophisticated climate models. The other popularly cited climate record, of the East Anglia research group, leaves essentially the same residual in an analogous comparison.

A slightly different analysis finds virtually no change in conterminous U.S. temperatures over the last century, which is consistent with some transient climate models, in which areas the

Region: NATIONAL



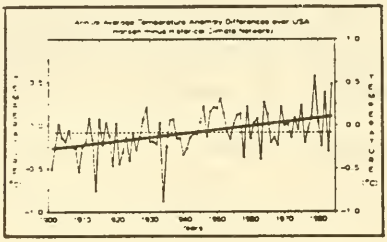
U.S. average temperatures in the urbanization-adjusted Historical Climate Network of Karl *et al.*. UL: Daily Maxima; LL: Daily Minima; UR: Daily Average; LR: Daily Range (Difference between high and low). The decline in daily range occurs because of a relative rise in nighttime temperatures, indicating that the possible greenhouse compensation is taking place primarily at night, while daytime temperatures have actually declined.

Analyses through 1987 show that this trend has continued.

size of the U.S. can continue to be cooler than the rest of the world for periods of decades. However, analogous studies of Canadian data and my mean layer temperature calculations for Alaska show that indeed the area of no significant temperature change over the last 50 years is virtually all of North America. It is doubtful that this can be accomodated by a transient climate model with a realistic change in trace gas concentrations over that period.

It would be important to extend these types of analyses to other regions with analogous urban/rural climate networks, such as the Soviet Union. I urge that you give what would have to be a joint effort your highest priority. In addition, I urge the support of other important investigations that will help us determine the earth's true temperature history and to find in fact how the change in trace gases will eventually be expressed.

These observations are not intended to minimize the importance of the climate change problem, but rather to emphasize its complexity. I find it extremely risky to enact sweeping environmental policy based upon visions that are at best clouded, and at worst already failing. Further, if models that eventually fail are used as the lynchpin for an otherwise rational energy policy, that policy could eventually suffer a serious loss in credibility which would set back progress on these important issues for decades.



NASA's record over the coterminous U.S. warms approximately 0.4° C compared to the urbanization-adjusted historical climate network. If such a trend occurred throughout the rest of the world, net global warming for the 20th century would be 0.2-0.3°C, which is virtually indistinguishable from background noise.

Mr. SHARP. Thank you very much, Dr. Michaels.

We are confronted with the proposition of trying to figure out when we're going to know what, and while we wait for more information, what do we do?

And, Dr. Albritton, you outlined the work through the United Nations and the international groups, suggesting that we'll have some stronger consensus statements about what we do know sometime at the end of 1990.

Dr. White, you indicated that we're going to step up the Federal budget, assuming that Congress goes along.

Let me first ask you, give me some rough projection as to when you think we'll have, in a sense, a new tier of certainty or knowledge? Is there any breaking point that we can expect that we'll really—that somebody will be able to walk in here and give us something that is qualitatively different from what you folks have given us today?

Does anybody want to make a rough projection on what is obviously an unknown?

I guess what I'm trying to get at, the question is whether if we wait around 5 years, we're really going to know more, or are we going to be with some additional information but basically still in the fundamental quandary of having to make policy on our best guess as to what the risks are?

Mr. MICHAELS. Well, I think it depends frankly on what some findings are in the next few years. I pointed out the importance of taking a look at this distribution of whether the warming compensation is taking place at night at other places around the globe. That's a study that could be done, probably with a minimum of effort.

As far as the modeling side of the problem, I think Dr. Schneider should answer on that.

Mr. SCHNEIDER. It's, of course, a legitimate policy question. How long is it going to take you guys, in this case us, the scientific community, to have a reasonable chance of increasing certainty over both the change in the observed world and in the model world as well.

The model well, the area where people want us to provide the most information is the area where I'm afraid we can give you the least, and that's the time-evolving changes in locations, what's going to happen in Iowa, Indiana, and India and when. It's much tougher for us to say anything reliable about whether it's wetter or drier in the Midwest in 20 years than it is to say that the magnitude of global warming is 1° to 5°.

So what are the timeframes? Well, for the reasons that my colleagues gave earlier, this problem cannot be approached as an atmosphere-only problem, an ocean-only problem, or a problem that looks only at the trees or the soils. But we have to literally couple all of those so-called climatic subsystems and then run them forward in time, and we can't just drive them by doubling CO_2 or some equivalent amount of trace gases, but we actually have to put in one of those curves I showed earlier, which is a time-evolving curve, an exponentially growing scenario for greenhouse gases.

The problem is that what we know is the rate at which the Earth is being heated. I don't mean warmed; I mean heated, the extra energy that is dumped at the surface. That's where the certainty is. But to translate that heating into local temperature and rainfall, we have to find out how the middle of continents are warming relative to the middle of oceans, and oceans mix at different rates in different parts. And in order to have some reliable estimates of those, I'm going to say that at the present state of the art, with the present relatively disaggregated effort in the scientific community, we're looking at several decades. Several decades is the time at which the real world system will begin to perform the experiment for us.

Now it's possible that some kinds of research could accelerate that date, and I wouldn't want to promise that in a decade from now we'll have definitive answers. But clearly if the policy timeframe for the system having serious effects is decades, and the timeframe for the scientific community producing reliable estimates is decades, then you have a legitimate question about what hedges you might want to take in advance, and one of those hedges, certainly in my opinion—and I have a special interest in this, so obviously you have to recognize that—is accelerated research, because accelerated research means not that we'll have a definitive answer, but that we will probably build consensus quicker, and that would make whatever decisionmaking that is incrementally applied on a firmer factual basis.

Mr. SHARP. Let me let the other two gentlemen have a shot at the question, which is to try to give us just a greater sense—I know you can't give it exactly—of whether we're going to qualitatively know a lot more or can, by accelerating research, know a lot more in the next 5 years. I'm articulating the question more sharply each time I do it.

Mr. WHITE. If I could rephrase the point——

Mr. SHARP. Sure.

Mr. WHITE. I think you're raising the question as to whether we can learn faster than the problem gets worse. In other words, by investing more in research and development, can we learn faster than the problem gets worse?

I don't think anybody knows the answer to that question. We know where the deficiencies are. We know where the uncertainties are in the mathematical models, and we know there are some things we can do to reduce those uncertainties, and we know where there are uncertainties in the data, as was shown here today, and I think we know what to do to reduce those uncertainties. But those uncertainties are not going to go to zero. There's always going to be a significant measure of uncertainty, even though for a period of decades.

I think the question we've got to face is, given the possibility of the consequences of a climate change, because we do know with certainty that the infrared gases are increasing, and hence the heating of the atmosphere is going on, are there some actions that we can take now that will not preclude, okay, our ability to take other actions, if indeed it turns out that this does not turn out to be a consequential problem.

I think the answer to that has to be yes. There are certainly actions that we can take with regard to increasing our energy efficiency. People have mentioned those. There are actions that we can take for reducing infrared-absorbing gases, such as the CFC's, by going farther than the Montreal protocols indicate that we now are at.

Now we know that those will essentially be beneficial, at least in terms of reducing the amount of carbon dioxide. If there are no adverse effects to these courses of action, then why not take them? That seems to me to be the point we're at.

Mr. Sharp. Dr. Albritton.

Mr. Albritton. Let me raise two points. One is to underscore a facet of the problem that I think all of us have alluded to, but perhaps should be emphasized, because it makes your job and it makes our job more difficult, and that's the time delay between the arrival of predicted warming and the application of the forcing—that is, the introduction of the greenhouses gases, and basically it arises because of the large thermal inertia of the oceans, and it's difficult for us to predict the exact timing of that delay and what it does to present observations of warmings.

But I think the point that that introduces into the dialogue between science and policy is exactly the same one that was introduced into the stratospheric ozone issue, and that is, in both cases we know—the understanding is good enough to say that because of the timelag, that actions later would, if they are, say, predicated under a fuller understanding that would justify strong actions, because of the timelag, actions later would necessarily then have to be more severe than actions earlier.

So the nature of the timelag introduces an element into the science policy discussions that I think should be very clearly placed on the table there.

The second point in terms of whether a greenhouse trend had been observed or not observed at the present is one on which there is a great spectrum of opinion, and I think most people realize now that it's very difficult to call that one. But probably more important than asking whether one has seen an effect, it's more important to ask the question about the statement that all four have alluded to here, and that is, most climatologists, most atmospheric scientists at present believe in the fundamental principles of trapping radiation by greenhouse gases, and as we all have stated, that ultimately the increase of such gases in the atmosphere is in the direction of global warming.

Now the timing and the amount of such is what we've been discussing about the debate, and therefore what I would urge you to pay attention to in terms of some near-time help, near-term help from science, is in the heightened discussions and debate over the next year or two, whether it be through this international assessment that I've described or hearings like these or scientific publications or special conferences, has the conviction of the scientific community weakened in that statement, that increasing greenhouse gases will ultimately lead to a global warming?

And it ties back to my first point, and that is, if it does lie in the future, if scientific opinion is right, and if there is a time delay, then perhaps the issue of whether it has or has not arrived is not as important as the scientific belief in whether it will arrive or not.

Mr. Michaels. I might emphasize that the problem is simply not scientific in what we would consider the traditional scientific realm. There's a problem that eventually devolves into economics and cost, and consequently that means that we are dealing with what may be the greatest systems analysis problem to ever come across the line. It's not simply, will it warm up, but, in fact, what will that do, and what will that cost?

And that's why we have to be very careful about the ranges of estimates that are given on this. There is a tolerable warming. Nobody knows what that is, at which it might, in fact, be counterproductive to be overly interventionist.

I think the economists have to be brought into the picture here to tell us, in fact, what that value would probably be.

Mr. SHARP. Do any of you doubt—let me put it this way. Dr. White, the National Academy of Sciences and National Academy of Engineering have made a general, with some specifics, recommendations to the President, and, I assume, to the Congress as well as to prudent steps that we ought to take. They do not seem to me at this point to be grand interventions in the economy or dramatic changes in lifestyle, but they do require us to take actions on energy efficiency, on deforestation. There were several other items that slip my mind at the moment. And they suggest, though, that we not wait for further scientific evidence to do that.

Is there any doubt that we ought to be taking prudent steps along those lines? There's always a cost-effective argument. My own assumption is that our system is overwhelmingly designed to preserve the status quo and that the risks of overintervention, they will be large in speeches and in the news media and in congressional debate, but in terms of real action, one seldom sees such grand interventions that society collapses.

What I'm curious about, whether you think the prudent course is to act upon what we know now, rather than waiting 5 years, in the sense along the direction as articulated by the National Academy of Sciences?

Mr. WHITE. Well, of course, our recommendations do indicate that we think action now is desirable, but actions of the kind that do not preclude options in the future. There are a number of actions that would be desirable from many points of view. They either make economic sense, or they would assist us with the acid rain, and other environmental problems such as biodiversity. There are many positives, and if we can take courses of action that have lots of positives and very few negatives, and the actions represent insurance policies against the possibility of a significant climate warming, to us it makes good sense to head in that direction.

Mr. SHARP. Dr. Schneider? This is a very complicated question. I understand that. I would like you, if you can, to keep fairly brief, because I owe it to my colleagues to give them a chance.

Mr. SCHNEIDER. Briefly as I started out earlier saying, what to do about it is a personal value choice, but you asked, so I'm delighted to answer.

And in my value system, I am not a gambler with the planet, and I believe that military funding is appropriate, even though we don't use economic calculus to determine that we have a military. We may argue over how much to spend, but we use strategic logic. It isn't simply a cost/benefit analysis.

We also use noneconomic logic to have national parks and so forth. The question is, does some degree of planetary insurance make sense? In my value system, yes, and what to do specifically is the question, and I agree with what we've called the tie-in strategy, which is to try to do those things which do—I can't say no harm, Bob; I think there's nothing you can do that doesn't do some harm. My favorite expression in ecology is that in nature you can't do just one thing. That's also true in politics.

If one is going to use energy more efficiently, undoubtedly there are some people who produce certain forms of it that will be hurt. So the question, then, is finding the politically appropriate way to set the right signals.

If I may, Mr. Chairman, read from your testimony 4 years ago when we had a similar discussion on energy efficiency, we were talking about the frustrations of the inability at that time to have any political reality from our beliefs in energy efficiency. It was important from both strategic and environmental points of view, and you stated:

> So my heart lies in that direction. I have no political illusions about any possibilities of that happening any time soon, and I must say in response, I am partly convinced that in many instances the market would drive it faster when the price went up than when we were able to get the regulations out to cause anything to happen. So I have a new respect for the market to be able to do a lot of those things that we were fumbling around with. Unfortunately, the market doesn't do them all.

I think that statement is just as true today, and the crux of the controversy—we haven't been controversial enough, so let me start it—the crux of the controversy is how do you use the market, and if the market is used in the status quo way to which you referred, which is what we're doing now, I think it won't work.

The problem is that, while I believe in a free market, I don't believe the present market is free. I think it's rigged. It's rigged, because the cost of coal or oil or any other fuel is simply the cost of digging it out of the ground, transporting it, and the small profit margin that people have in making it. That's not the true cost of the fuel. The true cost of the fuel is also the damage from acid rain, the local air pollution, the risk of greenhouse change, and so forth. And if one had a user fee—and I guess I'll be honest and utter the *T* word, a tax—on fuels in proportion to the amount that they pollute—and not just fuels; it could be deforestation activities in some places or chlorofluorocarbons—then the right market signals would be set up for the kinds of energy efficiencies that we need in the future.

Indeed, when OPEC came along and dramatically raised the price with terrible economic consequences, since they did it instantaneously—it didn't happen over time—the energy efficiency in this country and others went way up. And in the long run, I would argue that our economic competitiveness went up. We paid a price in unemployment and in temporary recession.

So the question is, what are the kinds of signals that we can set up, so that a market works? You can't make a market work by having zero environmental price, on fuels. It simply won't work that way. But we can make a market work if we "intervene" to make it more efficient.

My argument isn't that the putting of a tax on fuels would be an intervention; in fact, the intervention has been going on for 100 years. It's been the nontax on fuels. This is restoring what, in fact, would be a free market, and we can't do that overnight. It will take time, because people will be hurt. And in the process, I think that we should use some of those revenues to help provide transition compensation to those people who would be differentially hurt.

Mr. SHARP. Thank you.

Dr. Michaels, do you think we should take an prudent steps? "Prudent" is the keyword, of course.

Mr. MICHAELS. Well, I would like to back off a little bit and put your question in a wider context, and it's a context that, in fact, concerns me.

The peculiarity of the greenhouse effect problem is that it upsets the normal correlations or coalitions of forces that exist around environmental problems. We see groups that would normally be at each other's throats—say, nuclear energy and solar power people—allied on this issue. We see various and sundry other groups in the conservation field and other energy interests that come allied on this.

The point is that when you establish this new correlation, which is very, very strong, the political pressures on you to act are almost—you can't get away from them. So I urge you to——

Mr. SHARP. Trust me. If you're afraid Congress is going to act——

Mr. MICHAELS. I won't worry about that. I urge you, though, to recognize that in terms of environmental issues, that the normal forces that would serve as checks and balances on this issue may not, in fact, be operating.

Mr. SHARP. Well, I just—what I would like to rather get from you is whether or not along the scientific—I mean, that may be—that is a possibility or a probability of what will happen in politics, just as one who's run through the electoral system on the Commerce Committee and the House of Representatives, a limited sphere of that, I can just tell you that the chances of this Congress—there's going to have to be revolution in this country before there is such dramatic change, because of the national media. I know it seems that way when the national news at night carries things, but when it finally filters through and everybody goes off to look at all the other problems that they face in life and everything like that, we just never quite get around to doing it.

So my greater worry is whether or not we are passing up the opportunity here to do some prudent things. Almost every radical proposal that will come into the Congress will never come out as radical, unless there's something—I mean, even at the most incredible, tense, pressured time on energy, we did some what people might see as radical interventions, and some of them, I think, now upon reflection were wrong. But I really am not worried about that risk.

At the moment, I'm just wondering whether you are at all worried about the risk that if we follow the line that you just took, we simply won't do anything more.

The coal industry in this country sure as hell doesn't want us to do anything that will cost them anything more on environment, and I can name each other industry. I don't mean to get personal about it. Each one of them will have some good economic reason why we shouldn't touch them.

The end result is, we won't touch, if we follow that line of thinking. All I'm asking you, are there prudent steps that you would take on this or not?

Mr. MICHAELS. Well, I'll give you the words of a Senator, Senator Wirth, who said that we should ride the global warming issue to essentially encourage policies that are a good idea anyway.

My answer is, why not just go for those policies and don't use this as an excuse, because someday you may lose the credibility of the issue?

Mr. SHARP. Well, if it's dishonest to use it, I agree with you. But if it happens to fit together, then I—you take every line of thought and argument that you can find in order to win the case. All those other policies have been before this Congress for 20 years now, and we have taken actions on some of them. We took some good ones last year, but they're all like this, compared to the potential of the problem.

And so what I'm saying to you is, would you therefore not? You don't believe that we should buy any insurance on the global warming.

Mr. MICHAELS. Of course I do.

Mr. SHARP. Oh, okay. Well, that's what I'm asking.

Mr. MICHAELS. The problem is, all of us agree, potentially it's very, very serious, and prudent action is certainly a good idea. You're not going to get me to defend burning the tropical rainforest.

Mr. SHARP. Well, there are people that want to do that. That's why I'm asking you. Should the U.S. Government be trying to work with others to slow down the depletion of the tropical rainforest? Should we be working toward cleaner coal technology? Should we be working to, you know, greater conservation?

Mr. MICHAELS. Again, perhaps I'm naive. I'm saying these are prudent actions we should be taking anyway, and most people will support them.

Mr. SHARP. They don't when it comes to putting the money where the mouth is in American politics, that is the problem that I have with what you say. Most people give lipservice to that in Congress and outside of Congress, but you get something up here to talk about really doing that, and, boy, is it difficult to get any movement whatsoever.

That's just a difference of opinion perhaps we have on how responsive the system is.

But, Dr. Albritton, I didn't mean to cut you out.

Mr. ALBRITTON. Well, you asked the question, is it time to take action, and as Steve Schneider has articulated many times and in very moving ways, that's beyond a question of pure science. It balances science's specific input with a variety of other things that fall within your purview.

As a NOAA scientist—that is, one who is focused on atmospheric and oceanic effects—let me state the scientific aspect that feeds into your question as the input that I'm best qualified to give. And that is—and we've all said it in several ways—it is the view of most atmospheric scientists that if the radiatively active trace gases continue to increase, that the ultimate effect on the planet will be a warming, a warming that is likely to be larger than what we have experienced during civilized times and comparable to those that we understand have happened since the last Ice Age.

It is that part of the scientific problem that I would urge you to follow as you assemble the pages in your portfolio that will make the case for or against an action. You can see it at the end of 1990 on the international scene in terms of the strength of the conviction or lack of conviction in that overarching long-term statement about the effect of these trace gases.

Mr. SHARP. Thank you, Dr. Albritton. I have more than used up my time, and I recognize my colleague from California, Mr. Moorhead.

Mr. MOORHEAD. Well, for a nonscientist, it's hard to pull all of these things together, but obviously our resources in fossil fuels are finite. They won't last forever, especially oil, and, of course, we're having troubles in the United States and in other places with the amount we have. We're told we have a lot over there in Saudi Arabia and the Near East.

But I guess from our point of view, we get to wondering, will those last long enough to really cause any real problem with global warming, because obviously the trend has to change?

And then insofar as what we do now in this country, can we make a real difference in the world with global warming, if it is a problem? And if we do, I gather from the testimony that's been given that, of course, if we can use a safe nuclear energy, rather than oil and coal, we're doing something about the problem. If we can use solar energy, like there's a major plant out in California, and many people in the warmer climates are using that, we can do something.

But I guess we wonder whether what we do will make a difference.

Then we're told in the Health Subcommittee out in California in a hearing they had out there that we're going to be able to have battery-operated cars within the next decade or two, because they're close to a breakthrough. Obviously if we have to make our electric power through burning oil and coal, we may not have accomplished too much.

But I just wonder what—if we could increase the use of nuclear energy and this high-temperature gas-cooled reactor being developed by the General Atomics firm in California, can perhaps create nuclear energy in a much safer way, and at the same time recover ocean water for use of water in places that are particularly dry?

Is that something that we should be moving toward, Dr. White?

Mr. WHITE. Let me give you some answers. I may not have the exact data.

Are the fossil fuel reserves in the world enough to cause the serious climatic warming that's predicted? Yes if you use coal. It requires the use of the coal reserves, because the use of oil and gas reserves as presently estimated would not be sufficient by themselves to cause a very serious warming. Perhaps somebody else here has data on that.

Can we make a difference in the United States? As I said in my testimony, this is quintessentially an international problem. We are talking about the global energy system, and we're talking about energy used in very diverse ways and for very diverse purposes. It's an enormously complicated problem. We could make a small difference, but not a real one, I don't think, acting unilaterally. We would have to have action taken globally by many countries.

With regard to passively safe reactors I think there's encouraging research now going on and I think it would be a prudent course of action for this country to make larger investments in the research to develop passively safe nuclear reactors. They would have to be publicly acceptable. That's not going to be achieved overnight. We are going to have to have a period of time in which you can demonstrate to the public that these are publicly acceptable from a safety point of view, and you would have to deal with the radioactive waste disposal problem. Here you have differences of opinion in the scientific community about being able to do that safely.

My own view is that the technology for safe disposal of radioactive waste deposits is moving along and that over the course of time we should be able to do that.

So I guess I would answer your three questions that you raised as I've just done, sir.

Mr. SHARP. Dr. Schneider.

Mr. SCHNEIDER. Yes, thank you.

I agree with what Dr. White said and would only add that with the public acceptability of the nuclear problem that we have a long way to go. Fortunately, we have some time to do it.

The single "best" solution to dealing with the insurance against greenhouse warming is using energy most efficiently, and we know that there are many, many arguments for doing that. It's cheaper, many people have shown by calculations, to improve end use efficient than it is to build new powerplants. Now one cannot indefinitely use energy efficiency; you still have to have primary energy, and we're talking about the United States in this case, so that we do need to do the research that he referred to.

One other point that is important, the role of the United States. It's been argued that the United States is about 20 to 25 percent of the greenhouse effect, so what could we do acting alone? We could only make a 10 percent difference.

Yes, it's true that if we had a heroic effort, we might make a 10- or 15-percent difference in the world, maybe perhaps even better if we had a super-heroic effort. And my argument really is twofold.

First is that if we're the only country to do it, then that would be economically foolish in the long run. However, it's very unlikely that we would be the only country. Somebody has to have moral authority, and it's very difficult for us to go to the Chinese, who are looking—remember the population multiplier showed earlier—who are looking at a low per capita standard of living, and tell them that they can't do what we did, that they can't use all their coal and develop their industries and so forth, unless we at the same time have shown that we have used our advanced technology and our better economic capability to do a better job ourselves.

But beyond that, we have to recognize that if over 1 billion Chinese are going to use their rather soft and dirty coal to develop, then at least let them use half as much. In order to do that, that means higher capital investments to get powerplants that are 45 percent efficient, which is at the state of the art in my understanding, not 30 percent efficient powerplants.

So that means they would have fewer of them. So we need to talk to the World Bank, for example, that's involved with providing loans and say, we're on your side for giving loans to the Chinese or the Indians to develop, even if they have to use coal. As a climatologist, it hurts me to say that, but you have to balance their need to develop with environmental pollution. But at least let's make sure that the infrastructure that developing countries build both to produce the energy and to use it is as efficient as possible, because what they build now will be locked in for 25 to maybe as long as 50 years, and that can make a very, very large difference in the amount of greenhouse gas buildup. And it's slowing down the rate of change that to me is what is most essential.

So the role of the United States is not just to simply cut a couple of percent off the world CO_2 findings, but to set the example, so that the really big numbers in the future, the large number of people who want larger standards of living, will produce much less pollution as they develop. And I don't think that will happen without our active intervention and help.

Mr. SHARP. Okay.

Mr. MICHAELS. I think one of the points I would like to underscore here is that nobody here seems to be saying that in fact the carbon dioxide concentration is not going to go up in the future. That is something we are going to have to live with. One point that has been neglected is that there are other trace gases that are thermally active. The chlorofluorocarbons we can do something about. It is going to cost people, I believe, till people are, in fact, willing to pay the price.

Methane is the major problem. The latest papers that I have seen suggest that 25 percent of the methane fraction airborne now comes from the burning of biomass. That leaves 75 percent that comes from sources that we are not so sure of. It is probably some combination of rice paddies and cattle.

The point is that no matter what interventionist policy we begin to pursue, you are also going to have to figure out how to live with the problem, how to adapt to it. I think that is something that deserves to be recognized in the heat of this debate.

Mr. MOORHEAD. Are these buildups of carbon dioxide reversible? Is it something that in time if the world started using better procedures or were careful with our atmosphere——

Mr. MICHAELS. The residence time is very long. If we stopped putting in carbon dioxide in the atmosphere today, we would still be above our background concentration, I would estimate, for what, 7,500 years?

Mr. SCHNEIDER. Hundreds.

Mr. MOORHEAD. But if we do start running out of fossil fuels and we use other sources of energy.

Mr. MICHAELS. But we are not going to run out of methane. That is the problem. Methane appears to be extremely population related. If it is produced by rice paddies, and many people think it is, you are going to have to change the entire agricultural system. We can barely get people to change their diet in the United States to make themselves live longer, and we are saying that somehow we are going to take 1 billion people who live on rice and say no more rice paddy agriculture. The point is that we are going to have to live with it, and I think that we need to really take a look at adaptational strategies involved in this issue.

Mr. MOORHEAD. I didn't mean to ignore you, Dr. Albritton.

Mr. ALBRITTON. I can't comment wisely on alternative energy sources. That is outside of our Agency's thrust. However, I did simply want to underscore the international aspect of the problem. That is, several of the witnesses have cited that it requires a global approach to the problem, and I think this is why many of us are willing to put an enormous effort in the next year to making sure that at least the science is internationally agreed upon and that offers at least a common playing field for the international discussions that must be addressed to more difficult things like balanced trade and other things.

Mr. MOORHEAD. Thank you.

I thank the gentleman.

The gentleman from New Mexico is recognized.

Mr. RICHARDSON. Thank you very much, Mr. Chairman. I want to commend the witnesses for their objectivity and their scientific contributions.

Let me just try to deal with some of the policy aspects that many of you and many of us seem to be dancing around. The first one deals with the whole issue of the multilateral approach. Some nations are good. Some are bad. I think just trying to get the CFC Treaty, the Montreal protocol, was a major undertaking, and I commend the administration last year for moving on this front. They didn't move very fast on many other fronts.

Dr. White, I noticed in the recommendations to President Bush you talked about CFC's, and I think Dr. Michaels mentioned that there is something definitive we can do about CFC's. Recommendation No. 2, I guess, is on page 2. You said that provisions in the protocol should be called upon to encourage deeper reductions in emissions of ozone-destroying chemicals, with a total phaseout of CFC's on a reasonable time scale.

Assuming that the United States, hopefully, will take the lead as we did internationally, what is your definition of a reasonable time scale in this country for us to phase out CFC's?

Mr. WHITE. I wish I could give you a number, but it depends upon the disruptions that would occur because of a total phaseout, not really by the producers but by people who are dependent upon the CFC's. So you would want to do it in a reasonable time, making sure that you had substitutes to provide for the various purposes that CFC's now provide. I don't want to pick a number out of a hat because we are certainly not talking anything before 2000, it seems to me.

Mr. RICHARDSON. You say before the year 2000?

Mr. WHITE. You are not talking about anything before the year 2000. I think 2000 would be the earliest. But that is just a horseback guess. You would need a lot of time for the system to adjust.

Mr. **Richardson**. Let me ask another policy choice that I think many of us possibly in the reauthorization of the Foreign Assistance Act will be faced with this year unless I am mistaken, and that is what happens when an amendment is offered on the floor of the House this spring that says that Brazil for its deforestation practices should not be given World Bank assistance for multilateral efforts because of their abominable practices with their deforestation campaign? What happens when those policy choices come suddenly?

I guess my question is you have all talked internationally about a need for a multilateral approach; what happens when the positive aspects of multilateralism, that is, perhaps giving the Brazils more loans to clean up their act, getting consortiums to be part of this effort rather than punish, what is the approach that we need to use with the have and havenots? Everyone seems to be calling for an international conference. What more do we need to do?

Mr. **White**. I just wouldn't presume to comment on what steps the World Bank or the United States working with the World Bank ought to take with regard to Brazil. I think we can make some general statements that we do want to encourage them to preserve tropical forests as much as possible. They do have a development problem down there. The question is to channel the development activities in Brazil in ways that are environmentally sound.

I am not quite sure how you do that, but there are some things we can do when you come to U.S. AID policies. It seems to me, we provide money, through our own AID programs to many developing countries. In making grants to these other countries we can emphasize the need to improve on the basic scientific and technological infrastructure in those countries so that they can understand and take those steps within their countries that could reduce CO_2 emissions, that is, more energy efficient plants and things of this nature.

So I think we do have some mechanism within our own government which we control where it seems to me we can encourage the move in the direction of environmentally sound practices.

Mr. **Richardson**. What is frustrating here is that unfortunately you are giving us the same answers, and I think the chairman illustrated this, the same policy choices that we have to face, and this is why the value, I consider, of scientists perhaps drifting into the policy arena would be useful.

Dr. Schneider, Dr. Michaels, Dr. Albritton, could you see what I am trying to get at in terms of what do we need to do? We know what the options are. We know we want to encourage Brazil. We know we want to do things in an environmentally sound manner. We know we don't want to alienate Brazil. But tell us what to do.

Mr. **Schneider**. It is a good and a tough question and there is no magic solution. The best that I think we can do is to slow down the problem by taking a lot of small steps. If you add up enough nickels and dimes, soon you have half a dollar, and lots of little things need to be done. We have to work at the psychological front, the economic front and the political.

Psychologically, as I said earlier, showing some moral authority from getting our own house in order. There is suspicion on the part of Third World countries, and it is not misplaced, that this is just another attempt of the imperialist powers to deny them their rightful development. If we showed that we were making some initial financial investments at home, then it would help to evaporate that argument.

At the same time, most Third World countries are not environmentally stupid, and in fact many of them are aware that their development policies are not even sustainable in the long run. Indonesia, for example, has a transmigration project to take the densely populated island of Java and move people off to Kalimantan and Sumatra.

So where they are moving them to is tidal plains, coastal lowlands which are being deforested by the Japanese, which has many ecologists very upset because these are fragile ecosystems which have high species diversity. Yet, if a tropical cyclone comes by in these tidal swamps in these areas that are just a little bit above sea level, those very villages that are being set up could be washed off even today, and if sea level rises a couple of feet over the next century from global warming, then the sustainability of that development is very low.

The minister of environment from Indonesia was directly asked that question by a former postdoc, a graduate student of mine. He said to the minister: "If it is so bad and you know it, why don't you just stop?" The minister responded: "What else do you suggest for us to do to get the $2.5 billion that we are being paid for those trees?"

The key is it is not ignorance but desperation. Poverty is, in fact, a environmental disrupter. So what we have to recognize is not only do we have to do things at home, which our chairman has reminded us is difficult, but we also have to do things overseas as well. We shouldn't be in despair because it is impossible to stop some buildup of greenhouse gases. I agree with Pat Michaels that adaptation is part of the story.

But if we can quantitatively make a difference, a doubling of greenhouse gases in the year 2050 is definitely worse than a doubling in the year 2100, and the rate at which things change is the problem. The faster things change, the more likely it is that we won't know what is going to happen, the more likely there will be nasty surprises and the more disruption. So if we can do a lot of little things and help provide incentives to those countries and show that what we are doing at home is adding some measure of sacrifice, then incrementally, step by step, we can make a difference.

Mr. RICHARDSON. My last question to Dr. Michaels and Dr. Albritton. I don't mean to prejudge your response, but both of you were insistent on the need for more research. On the uncertainty side, you probably signed off more than two other witnesses. I guess my question is: One aspect of the global warming has been the acid rain debate. You have heard of the inaction of the Congress and the government in dealing with the acid rain debate, and it has been because industry will tell and the previous administration was telling us we need more research, we need more research.

Do you see this, putting a future cap on, by the year 2000 that you will be sitting here and saying the same thing?

Mr. MICHAELS. No. First, you are going to have to balance the need for research with the magnitude of the problem. I am sure I am going to irritate a lot of people by saying that the acid rain problem is, in fact, not nearly as emergent or as important or as serious as the global warming problem if, in fact, the worst case global warming scenarios are true.

Now, we do see these very strange things in the temperature record where it looks like in fact these nighttime temperatures might be coming up. We see the disparity between the hemispheres, where the Southern Hemisphere is warming up much more greenhouse like than the Northern Hemisphere. Surely we have to understand these things before we go defending a policy in the Third World.

Dan Jaansen, who holds what is the equivalent of the Nobel prize in ecology, commented recently in Science Magazine that if we were to push the reforestation solution on people who live on marginal agriculture in the tropics, we will be disrupting the way of life of 1 billion people.

All those people have to do is say, wait a minute, we know that there is something fundamentally wrong with our understanding of this problem with respect to certain temperature curves or with respect to nighttime, daytime warming, and we are not going to go along with this. So in order to assure you can defend the policy, we have got to do a little bit more work on it. I am sorry. I am not dragging my feet. I am trying to make sure we do the right thing and get the right answer.

Mr. ALBRITTON. I would assume that in policy, as it is in science, there is a hierarchy of actions. That is, there is a zero thought or action, a refined action later, and further refinements after that. So the question is what hierarchies of understanding of science are available to help you with these zero, first and second order decisions.

What I have tried to emphasize is that in thinking globally and in thinking of the longer term and in thinking of the fact that once we discover we are dealing ourselves a losing hand, we can't quite quit the game so easily. The zero thought or science statement that I think is of most utility for you in the next year or so as you focus on this zero thought or policy action is the statement that most scientists feel that if these greenhouse gases continue to increase unabated, that it is very likely—which are fairly strong words for scientists—it is very likely that warmings will ultimately occur, perhaps not in our lifetime but perhaps in our children's lifetime, that are on a scale that we have never experienced as a civilization before.

That is a zero thought or statement that I urge you to watch in the next year or so to see if anybody with their new research turns it over. I think that is the statement that would match more closely to your zero authority needs.

Now, in underscoring the need for more research, I try to emphasize that you are going to have to make later decisions involving regional problems, and we simply cannot offer you good advice on regional problems yet. In my written testimony I tried to outline how we can improve that, how we see angles of research that must be done in order to be of better service to you in terms of later and second order decisions. I tried to divide it up into those two levels of uncertainty and knowns from the zero thought or estimate, from an ultimate refined estimate that could come later.

Mr. SHARP. Thank you.

The gentleman from Tennessee, Mr. Cooper.

Mr. COOPER. I thank the Chair.

One of the hardest things about politics is that very few people listen to the nuances of what you say. There is an inevitable cartooning tendency. It seems to me that from this panel most Americans will probably never be aware that all four witnesses were in substantial agreement. The reporters will probably highlight the differences between Dr. Michaels and Dr. Schneider, and I think that we should thank the two gentlemen for being willing to engage in polite argument over some of the nuances of the issue.

But we shouldn't forget that in the larger scheme of things, these are nuances. It is not a headline, you know, "Chicken Little versus Paul Revere." Everyone on the panel, in my opinion, is a Paul Revere of sorts. Some people want to ride faster than others. Dr. Michaels may even want to walk until he is very sure of the direction he is heading. But it is important for the public to realize that since the timelags are so great, that we need to begin the journey now.

The vested interests are so powerful and so overwhelming, as I believe the chairman has stated, and I believe his phrase was the risk of overintervention is small. That is the strongest form of understatement I think I have ever heard.

So to me the bottom line message is that all panelists are in substantial agreement. Their differences are of degree, not of kind. You all think action should take place; it is a question of how the action occurs.

Dr. Michaels, I see you squirming. Would you like to say something?

Mr. MICHAELS. The reason I am squirming is because I tend to agree, by and large, with your statement but I have seen others in the government make statements that people who express what they characterize as the contrarian point of view—and I guess that is me—are doing a disservice and they are, in fact, impeding our ability to act on this issue. I would like to submit that knowledge, in fact, is power, and if there are some things that we have to know, a person who brings up the fact that there might be some critical factor here that we are not looking at is by no means irresponsible but, in fact, trying to protect our policy on this issue.

Mr. COOPER. I just hope those people you are referring to, I hope that you realize they are helping you build a career and that is not a small side benefit. You also have to realize that in the inevitable cartooning tendency, there are people who want to paint you unfairly as being antigreenhouse effect. You have to resist strongly that tendency and that characterization.

Many people don't realize that in Washington anything can have a lobby representing it, even scientific uncertainty. That is probably one of the biggest and best-funded lobbies if you are talking about tobacco smoke, for example. So please bear in mind that there are people who would like to use your testimony to shield less noble causes.

So to me it is difficult to mesh science and politics. We speak two different languages, as has been pointed out many different times, but please bear in mind the timelag necessary. If you were to issue a clarion call for action today, Congress might act a decade from now. All of you have already pointed out that these anthropogenic effects have already been in place. Even if we stopped production of chlorofluorocarbons, the effect would last probably well into the next century.

The American public generally does not realize that, so in communicating with the public, some politicians have on occasion been guilty not of understatement but of overstatement. I don't think it is the wish of any politician to seem antiintellectual or antiscience. I hope that you are willing to forgive overstatement on our part sometimes as we are willing to forgive overcautiousness on your part. We play by two different sets of rules, and I think we are more sensitive to timelags in public understanding. You are probably more sensitive to the timelags in the oceans and the thermal lags involved there.

So to me, bridging the two cultures is hard and I would appreciate your forebearance as much as possible. To me the differences between you and Dr. Schneider are so small they almost boil down to stylistic differences. In fact, to me you almost seem like the Amy Vanderbilt of this because you are concerned that he might have used a wrong phrase or might have overreached on occasion or perhaps his hands might have been scientifically a little bit dirty.

It is important to point those things out, but don't let yourself be used by folks who do not share your interests for scientific purity, because the tendency is out there. The vested interests are strong. I hope the message goes out from this hearing that you are in substantial agreement, not that there are some people who want to act and some people who think we can afford to wait decades before we moved.

I wish we lived in a perfect world in which acknowledgement of a scientific risk could mean appropriate action. The lag is so great, however, that sometimes politicians are perhaps overanxious to go ahead and act so that when the time comes, we will have taken at least the beginnings of appropriate steps.

Mr. MICHAELS. Yes, but I will point out that the range of scientific opinion on this in terms of the amount of warming that one would expect or how that warming would be distributed, which is very, very important in its effect, that range of opinion is, in fact, quite broad at this point in time. I do you a disservice if I tell you that everybody thinks one discrete thing is going to happen.

My major concern, though, is I find it a much more difficult and challenging problem to deal with a range of future uncertainty rather than a specific forecast. That is why you have to be very, very prudent and very cautious in your action.

Mr. COOPER. I think it is fine to point out that range and the significance of the range. It is my feeling that virtually every panelist pointed out that range at least indirectly today. I think you have served a very valuable function in the debate. The Nation was looking for someone they could paint as antigreenhouse. You have served that purpose for the time being. But now that everyone is clarifying their approach and using more precise language, to me perhaps another approach might be helpful in pushing us along toward greater understanding.

I, for example, found interesting—to get specific for a second—a Connecticut electric utility, I believe, has leased or arranged somehow to plant a lot of trees in Guatemala. To me that is an interesting private sector initiative that acknowledges some of the externalities that are associated with a private powerplant.

Getting practical for a second, there will be people who oppose initiatives like that for other utilities. Those people in public meetings will cite your name and your reputation and say that you agree with them. We need to be careful. I would like to get your feeling on the Connecticut example, but my guess is you wouldn't think that is a terribly inappropriate action. It perhaps is insensitive to the interest of the Third World, but——

Mr. MICHAELS. Again I would only point out that Dr. Jaansen, who I believe is at Penn, did say we would have to be careful in these reforestation programs because they can, in fact, create major social unrest.

Mr. COOPER. That is true, but when we pay for the right to plant trees, perhaps they are also getting a benefit that could alleviate terrible social problems today. Perhaps when we educate Brazilians that when they clear the forest, the subsoil is inadequate to sustain cattle ranching for longer than a year or two, they could see what is really in their long-term interest as opposed to their short-term interest.

So I would urge you to be cautious because there are people everywhere who will want to use what you say, not as you intend it but to slow, if not halt, any action, and by then it might well be too late. That is the fear that I think most policymakers have, the difficulty in communicating between the two cultures.

I am sure my time has expired. I thank the chairman.

Mr. SHARP. The gentleman from Utah, Mr. Nielson.

Mr. NIELSON. Thank you. It is difficult to follow that philosophical discourse.

I am sorry Dr. Schneider left. I had several questions for him which I would like permission to submit to him for the record.

Mr. SHARP. Certainly. He indicated he had to go on another hearing that was being held.

Mr. NIELSON. I understand. Let me ask the questions and let the other people take a crack at them.

Dr. White, I like your idea of taking courses of action which have positives and very little negative and which can only help and would not preclude further action later as we gain more scientific information. I think that is a responsible situation.

Dr. Schneider said some interesting things. He said we should have a tax or a fee proportionate to the damage caused by various actions, CFC's, fossil fuels, and so on. Our chairman indicated we are having trouble with acid rain and the coal people don't want to do anything. Let me see if I can tie those together and see if Congress has not maybe made a bigger problem than it should have.

When we passed the Clean Air Act, I think Mr. Sharp was a member of the committee when that happened, and we said we will take the coal as it stands and we will reduce 70 percent of the sulfur dioxide out of that coal by scrubbing. It doesn't matter how dirty the coal is; we will take 70 percent. We will take the same percentage off from the clean coal as we do from the dirty coal.

So what we have done is we take high sulfur coal, which after being scrubbed, is still dirtier after the 70 percent reduction in many cases than some low sulfur coal elsewhere in the country. That was certainly not based on what the adequate level would be. It was going to force everybody to do the same percentage reduction.

Second, we say we will solve this all by clean coal technology, and yet our bills that we talk about in acid rain preclude fuel switching or any washing or anything which could reduce the sulfur naturally. Third, our World Bank was mentioned. We should help China develop their coal reserves, their resources, make sure that they use their dirty coal, but let's make sure they get 54 percent efficiency instead of 28 percent and so forth.

Our World Bank has a terrible record. I am sorry Mr. Richardson left because it affects his area directly. The World Bank loaned money to Mexico to build the Cananea refinery, a copper refinery, and also one in Narcazona. They don't require any scrubbing in those plants, so those refineries billow their sulfur dioxide across our border without the scrubbing, and with World Bank financing. At the same time, they destroy our copper refineries, primarily in New Mexico and Arizona, but Nevada and Montana as well.

It seems to me like our World Bank has not really helped the problem. If the World Bank would say to China, build those efficient coal ones but also scrub them before we will lend you the money, maybe they would really be an instrument to help. But if they don't require the atmospheric and the environmental things along with it, it seems to me like it would be counterproductive for the World Bank to push the electric industry.

I would like any of you to comment on these industries. I represent a very high quality, low sulfur coal State, as you might have guessed. I have had a private complaint about the Clean Air Act as being regionally insensitive to the differences in the area.

Do I make any sense or am I completely off base?

Mr. WHITE. You certainly raise a lot of fundamental questions. There are many ways to skin a cat, is what I hear you saying, and that we may not be skinning the cat in the right way. We as scientists can say something about how much of the emissions, sulfur dioxide and others, that go up will come down, and we can say something about what their impact will be and we can give you some recommendations on the extent to which you might wish to cut back those emissions. Then you head into the kinds of problems you tackle up here on the Hill: who pays, how do you pay, who carries the burden? Those are the kinds of things you are talking about.

Obviously, the Western low sulfur coals are much to be desired in firing electric utilities. Set against that you have the other problems of the high sulfur coal producers. You arrive at a compromise up here, which may not be the best compromise in the world but it certainly is a step in the direction of reducing the sulfur dioxide emissions. I guess that is the real world.

I think that there is a general movement in this country and others that we have to use more economic incentives to take into account externalities. It seems to me that is a general way in which to go. That is easy enough to say; it is hard to do. If we keep pushing and using such incentives, I think that gradually we will get where we want to go.

With respect to the World Bank, I think you cite an example which really characterizes the problem very well. I would hope that our representatives in the World Bank in making loans would want to talk to the Chinese or the Mexicans or any other country when they make a loan for any energy production facilities or other kinds of industrial facilities to ask and even take some strong steps to make sure that those are as environmentally benign as one can make them with modern technology.

It is not always possible, but it should be our goal, it seems to me. I would certainly urge that those are the kinds of positions we ought to take in the World Bank.

Mr. NIELSON. Thank you. It seems to me if the World Bank is going to help develop industrially these backward countries and these developing countries, it ought to also stress what they are doing in the environment and include that as part of the loan. That is my point.

The second thing I was going to mention is I notice that the trends—and by the way, Dr. Michaels, Mr. Cooper mentioned you might be viewed as biased. I think tipping them the way you did on the screen made them look flat even when they were, in fact, rising in some instances. I know that was not intentional and your machine didn't work very well, but I thought it was very cleverly done. I used to be a statistics professor, and one of the texts is "How to Lie with Statistics." Your visual presentation made it flat and slightly declining even when it was rising.

Mr. MICHAELS. The projection was distorted, not the interpretation.

Mr. NIELSON. Even in spite of that, I was able to detect that things went down from 1930 to 1972 and then they rose from 1972. What accounts for that apparent decline for a quarter of a century and then an increase recently?

Mr. MICHAELS. That depends upon, frankly, which theory you aspire to. Some people will tell you primarily it is a function of volcanic activity, particularly the explosion of Mt. Agung in 1963. I am not so sure, in fact, that is the case. I think that there is a certain level of variability in climate, which I will call natural only because we can't explain it, and that is in fact what that is.

Therein lies an interesting problem that many scientists have pointed out. Pulling the greenhouse signal out of the climatic haystack, if you will, the noise, is going to be a very, very difficult proposition. It is not so sure that we even know what the real level of variability is. Dr. Schneider has been sitting on a paper I submitted to his journal for a good year now that says it is twice as much as we used to think it was.

Mr. NIELSON. But the global temperature going down from a period of—it increase from 1880 to 1938, then decreased from 1938 to 1972, and now we are on the rise again. What do we know would cause that? Dr. Albritton or Dr. White? Also along with that same question let me ask the other one.

According to the philosophy and according to the predictions of Dr. Schneider and other groups, it should have risen quite a bit, and yet in fact it has only increased by 0.2°C. Why has it not warmed to the extent it was predicted?

Mr. MICHAELS. Nobody knows. That is the problem.

Mr. ALBRITTON. I will underscore that. We simply don't have the ability to explain the temperature changes, the nature of the temperature changes, particularly on decadal scales that we have been observing the last 60 to 80 years. We can't explain the warm eighties in quantitative terms. If we had that, that means we could imply what the next decade is going to be in terms of temperature, which would obviously have large investment, grain future prospects. No climatologists are rushing into that investment field.

Mr. NIELSON. Yet Dr. James Hansen said our drought last year was probably caused by various things which cause the global warming and so on. My question is did he actually make that statement, No. 1, and No. 2, if he did make the statement, did he predict it beforehand or did he simply use this and say that is the phenomenon which proves it? What is the actual fact?

Mr. MICHAELS. No, he did not make the statement.

Mr. NIELSON. I know he didn't, but I have heard that statement made by many people, and articles and so on say Dr. Hansen is the authority and says this was the result, we are going to get a climate change as obvious proof that this is happening. No. 1, tell me what he did say? No. 2, was it after the drought that we observed or was it predicted in advance of the drought?

Mr. MICHAELS. I don't have his testimony in front of me. Do you have a copy of his testimony?

Mr. WHITE. No, I don't.

Mr. MICHAELS. I will try and remember it as best I can. He said that there is a high degree of cause and effect between recent temperatures and anthropogenic activity in the atmosphere. Then he took some of the temperatures in the 1980's and compared them to a mean from 1951 through 1980 and found, in fact, that some of these temperatures were three standard deviations away from the mean.

Mr. NIELSON. So he is 99 percent sure that——

Mr. MICHAELS. Yes, but you as a statistician know that in fact such a number does not imply causation. That is where I think the misinterpretation occurred in the popular perception of his testimony. I have to ask myself, frankly, if in fact, given that testimony had been reviewed, I am sure, that I wonder if people knew that was going to happen that that misinterpretation would have been made. I don't know the answer.

Mr. NIELSON. Would anyone else like to comment on that?

I understand what he means by 99 percent sure, three deviations away, I understand that, but do you agree with that statement?

Mr. MICHAELS. It was three standard deviations away from the mean, but to say it was caused by anthropogenerated carbon dioxide, you can't. As a statistician you know that.

Mr. NIELSON. I want it for the record.

Mr. WHITE. Mr. Hansen isn't here and not able to defend himself.

Mr. NIELSON. And neither is Dr. Schneider. I wish they were.

Mr. **White**. But there is a statement by Mr. Hansen in the New York Times on Monday, January 2, 1989 which clearly expounds his view, and I think it would be useful, therefore, if that statement could be made available.

Mr. **Sharp**. Without objection, we will make it a part of our record.

[The article referred to follows:]

[From the New York Times, January 2, 1989]

HOT SUMMERS IN 1990's

(By James E. Hansen, Head, National Aeronautics and Space Administration's Goddard Institute for Space Studies)

TO THE EDITOR: The summary of my view of the relationship between the greenhouse effect and the 1988 heat wave and drought ("Scientists Link 1988 Drought to Natural Cycle in Tropical Pacific," Science Times, January 3) is misleading. It states that I agree with Kevin Trenberth's analysis relating the drought to equatorial Pacific temperatures, and implies that I believe the greenhouse effect is not yet a factor in heat waves and droughts.

Every drought can be related to such climatic circumstances as the position of the jet stream, soil moisture, snow cover and ocean temperature patterns. That will be true even if the greenhouse effect greatly increases the frequency and severity of drought. Dr. Trenberth's analysis, relating equatorial temperatures, atmospheric waves and the position of the jet stream, is excellent and may have captured key factors influencing the 1988 drought pattern.

Other climatologists will place greater importance on, for instance, ocean temperature in the North Pacific and antecedent soil moisture conditions. The ultimate test of theories about seasonal climate fluctuations will come when they are applied to seasonal predictions before the fact, not 6 months after.

As I testified to the Senate during the 1988 heat wave, the greenhouse effect cannot be blamed for a specific drought, but it alters the probabilities. Our climate model, tested by simulations of climate on other planets and past climates on Earth, indicates that the greenhouse effect is now becoming large enough to compete with natural climate variability.

The model gives us a hot summer in the United States in the 1990's about 60 percent of the time, compared with 33 percent for 1950–79. By 1989 this probability has reached 50 percent in the model. Droughts in the United States increase similarly in the model. These are hard predictions, which will be tested in the next decade.

We know from paleoclimate variations on Earth that greenhouse gas changes have been a principal mechanism for large global temperature changes. Manmade greenhouse gases added to the atmosphere in this century are beginning to rival in amount the greenhouse gas additions associated with past climate changes from glacial to interglacial conditions. The observed global warming of 1°F in the last century is consistent with the expected warming from the growth of greenhouse gases in that time. I believe this empirical evidence, with the theoretical model studies, is ample justification for my testimony that the greenhouse effect is changing our climate now.

There are many uncertainties in predictions of future greenhouse climate effects, but these do not alter the conclusion that large climate changes will occur in the next decades if we continue rapidly to emit greenhouse gases. I believe we should take steps now to reduce the greenhouse effect that would make good policy anyhow. Examples: phase out chlorofluorocarbons (which destroy ozone and cause 20 percent to 25 percent of the greenhouse effect), improve energy efficiency (reducing dependency on foreign sources of energy and improving our balance of payments) and discourage deforestation (preserving the habitat for invaluable biological species).

Mr. **Nielson**. Dr. Albritton, did you want to comment on that?

Mr. **Albritton**. No, I have nothing more to add on that.

Mr. **Nielson**. Do you have any explanation for the fact that the temperatures went up and then down and then back up again?

Mr. **Albritton**. Our understanding of short-term fluctuations is simply not that good.

Mr. NIELSON. What do you mean by short term? Fifty years and 26 years?

Mr. ALBRITTON. Decadal changes of mean temperatures.

Mr. NIELSON. You call those short term?

Mr. ALBRITTON. Those are short term in terms of trying to predict.

Mr. NIELSON. It depends, I guess, on what school you went to.

Mr. WHITE. One last comment. Climate fluctuations are known and documented to have occurred on all time and almost all space scales. In the historical record, man's record, we have had events such as the Little Ice Age, where you had very extreme cooling, at least certainly in Europe and other parts of the globe, for a period of a century or so.

The internal dynamics of the atmosphere are sufficient to cause changes in the climate without calling on a variety of external effects. We know that happens. It has happened in the past and will continue to happen in the future. The tough problem is to extract a signal which is due to man's activities, namely, the increase in carbon dioxide and other infrared-absorbing gases, from the natural fluctuations in climate.

Mr. NIELSON. And yet the press will talk about El Nino and they will talk about destroying the ozone layer in the Antarctic and the Arctic and so on and come to rather strong conclusions and alarm a lot of people. What is the answer to that?

Mr. WHITE. I think the only answer to that is to be very precise when one talks with the press about what it is you have found and what the——

Mr. NIELSON. That is not a guarantee, though.

Mr. WHITE. One cannot control what the press writes, nor should one even seek to control what the press writes. One would hope that by being accurate and precise in the interaction with the press, you would get the correct story across.

Mr. NIELSON. Thank you, Mr. Chairman.

Mr. SHARP. I thank the gentleman.

Gentlemen, we will conclude in just a moment. I just had a couple more questions if you could help enlighten me.

The question of the urban islands of heat, I guess I don't understand the relevance or irrelevance of that. You keep pointing toward extrapolating that from the data.

Mr. MICHAELS. That is exceedingly important. I will give you an example of the urban heat island. It is well known that Washington's mean temperature at National Airport is directly proportional to the number of Federal employees. I don't mean to be a little flip with you, but it is because, in fact, the economic activity has created a city. A city has the effect of disrupting the normal airflow, and that results in temperatures in fact going up.

Now, it was thought that this effect was essentially something confined to communities over 100,000. Tom Karl has now shown that in fact it exists in communities down to 2,500. When we take Karl's record over the United States and take out all the urban warming and compare it to the Hansen record, the Hansen record warms up 0.4°C compared to the unurbanized record. The Jones and Wigley record, which is the East Anglia record, which shows a global warming of 0.4°C, warms up fifteen one-hundredths of 1°C because of the urban effect. It doesn't have probably as much contamination in it.

The question is does that effect exist worldwide? There is no argument that I can come up with, frankly, that says that it doesn't. If it does exist worldwide, that means that the absorbed warming in the 20th century has been something around 0.3°C. That is far less than what we would expect even with liberal arguments of oceanic thermal lag given a change in trace gases, which is effectively 151 percent increase in carbon dioxide. Effectively. It is not really. Again, you are making the other gases act like carbon dioxide there.

But therein lies the problem. I don't mean to appear as the Darth Vader of the environment by pointing that out. It is something that is very galling and very difficult.

Mr. SHARP. Is what you are saying that much of the warming may be attributed to the urban islands as opposed to the trace gases? I am trying to get what the bottom line is as to why we would want to do that. Then does that take you to the next step of what is relevant about that. Do we wish to or would we be wise to do something about the urban heat islands?

Mr. MICHAELS. Oh, no. No, no. I think urban heat islands, in fact, save on heating costs considerably. Air-conditioning in Washington is mandatory anyway in summer, so I don't think that is——

Mr. SHARP. A perspective given to me by the forest industry, so I take it for what it is worth, is that we need to do a lot more effort to get trees in the urban area to reduce that effect.

Mr. MICHAELS. You would be hard put to find anybody in this room against planting trees in cities.

Mr. SHARP. I mean for reasons of trying to affect the temperature and its relevance. It does have an effect?

Mr. MICHAELS. That is a demonstrated effect. The problem is keeping the trees alive. Los Angeles planted 1 million trees——

Mr. SHARP. And/or the people.

Mr. MICHAELS [continuing]. For the Olympics and most of them weren't tended.

Mr. SHARP. Let me ask you on the gases themselves just to help get a better perspective. A lot of discussion has been on CO_2, some on chlorofluorocarbons, some on methane. If we are at the phase of where we are trying to determine what are prudent steps—as I understand Dr. White, one of the more explicit and concrete recommendations is do more about chlorofluorocarbons. They clearly per molecule, as I understand it, are dramatically more heat trapping than is carbon dioxide, but if I understand it correctly, they are a much smaller percent of what is up there.

I guess in a sense I am asking you can we at this point—is there an area where we ought to emphasize more than another under a prudent step kind of philosophy of action? Given the fact that this has an effect on ozone thinning, is that where you put your money at this point? Dr. Albritton?

Mr. ALBRITTON. That is a good question. The Montreal protocol calls for a 50 percent reduction by the year 2000, and I and my colleague Bob Watson were the two scientific advisers to the U.S. delegation to the protocol, so I watched that spin through the whole process.

The science that we described to the U.S. delegation at that time, and which was accepted by the international community and hence was the scientific pedestal on which the Montreal protocol was based, has changed considerably in the last 2 or 3 years. I have been fortunate to be a part of that through the research side, the Antarctic ozone hole, the recent Arctic ozone campaigns.

What science can tell the protocol signers when they reconvene in 1990 to evaluate whether they have done the right thing, enough or need to do more or faster, we can tell them in terms of the science input to that that three rather remarkable things have happened since they drafted the Montreal protocol.

No. 1, the cause of the Antarctic ozone hole, the total weight of evidence suggests that it is CFC's, their effect being amplified in that region by the unusual cold temperatures and physical characteristics of Antarctica.

No. 2, is that a study of the global trends taken from ground base measurements over the Northern Hemisphere have revealed a downward trend in ozone in the Northern Hemisphere that can't be explained by any natural variations and has similarities predicted by the CFC ozone destruction mechanism.

Then No. 3, the recent measurements in the Arctic, as my colleagues Adrian Tuck and Bob Wasserman reported just recently in the last few days here in this city, that campaign found that the same ice particle CFC processes that were discovered in the Antarctic also happen in the Arctic.

So the bottom line in terms of scientific consideration that the policymakers should take regarding the Montreal protocol and ultimately whether more or less CFC controls are needed is that every facet, all three facets of discoveries since the 50 percent was agreed to be justified go in the direction of additional ozone loss due to CFC's. That point, then, is the scientific input that they will have to weigh against availability of substitutes, pacing and so on that we cannot comment on.

But the science has been remarkable in the last 3 years in that area, and the picture that it paints is fairly clear.

Mr. MICHAELS. Chairman Sharp, can I show you something remarkable in response to that to show you how complicated these problems are? When I gave my presentation I skipped over a slide because I didn't want to take too much time, but in response to Dr. Albritton's commentary I would like to show it to you if that is all right.

Mr. SHARP. Surely.

Dr. White, did you have a comment while he is getting his slide? I thought you were about to speak.

Mr. WHITE. You wanted to know what might be done in the way of more specific and concrete actions. There is certainly a whole range of actions to be taken. I will just cite one. If indeed it is desirable to shift from coal to natural gas because it provides less CO_2, then you ought to take a look at what restrictions we presently have in this country and other countries on the use of natural gas which might preclude people from moving in that direction. So I would take a look at a variety of obstacles, and regulations that preclude doing what we want to do and ask ourselves a question as to whether those ought not to be changed.

Mr. SHARP. Thank you, Dr. White.

Since we removed all of the Fuel Use Act restrictions last year, and we are looking at the final price regulations, which frankly don't have much impact in the marketplace, but they do make a difference perhaps in what gets produced and how available it is, and we're trying to take that very seriously at this point.

Yes, Dr. Michaels?

Mr. MICHAELS. I think I've made it worse when I tilted the screen.

This shows the complexity of the issue and points up something that, in fact, feeds into the entire climate change problem. What this chart is, it's from a paper by Scotto, and others. It's trends in ultraviolet B radiation; that's the kind that causes skin cancer—across the United States as measured by instruments that were, in fact, specifically designed to do this and deployed in response to the debate over the supersonic transport in 1971. And most people will tell you—I'm sorry the way the screen and slide tilt—will tell you, in fact, there is a very significant trend down.

Mr. NIELSON. I apologize for even mentioning that.

Mr. MICHAELS. Now this is bizarre, because we——

Mr. SHARP. I'm sorry. I didn't catch what you just said.

Mr. MICHAELS. There is a significant trend down in ultraviolet B radiation across the United States. This is in the face of an ozone decline in the stratosphere.

The people who wrote this paper concluded that something—that there was an unknown or that the amount of attenuation of incoming radiation was greater than previously suspected. So when people talk about increases in cloudiness or increases in atmospheric turbidity complication what I would call the simple model of climate change, this, in fact, may be some evidence for that.

So we get an ozone decline, and still the amount of radiation reaching the surface that will cause skin cancer declines. Isn't that strange?

Mr. SHARP. And what are the mitigating factors that you speculate on?

Mr. MICHAELS. The speculation is that there are a number of reports that appeared in the scientific literature, in particular Dr. Schneider's journal, pointing to possible increases in cloudiness. And I think if you look at the testimony that Tom Karl submitted to you as background for this committee meeting, he, in fact, believes that that is also occurring.

Mr. SHARP. All right. Well, gentlemen, I want to thank you for your time and attention to us this morning. I know you are deeply involved in these issues, and we appreciate that very important scientific work going on and helping us struggle with how to sort through it and decide what we ought to do as a country.

Thank you very much.

[Whereupon, at 12:39 p.m., the hearing was adjourned, to reconvene at the call of the Chair.]

GLOBAL WARMING

THURSDAY, MAY 4, 1989

House of Representatives,
Committee on Energy and Commerce,
Subcommittee on Energy and Power,
Washington, DC.

The subcommittee met, pursuant to notice, at 10:36 a.m., in room 2218, Rayburn House Office Building, Hon. Philip R. Sharp (chairman) presiding.

Mr. Sharp. The subcommittee will please come to order.

Today we continue our investigation of what we should do about global warming. Every action that our subcommittee takes or fails to take has significant implications for the global warming problem and the global warming debate will significantly affect our deliberations on energy matters.

At our last hearing we learned that the environmental, institutional, political, and economic implications of global warming are potentially profound and today we will learn something about potential solutions.

The Environmental Protection Agency [EPA] will tell us about their long awaited draft report to Congress called Policy Options for Stabilizing Global Climate. It contains a wealth of information on the technical possibilities for achieving global environmental goals. We still need to know much more about what is economically and institutionally achievable.

I am looking forward to hearing what work EPA has underway to answer these important questions, what steps we might take and what they would mean. This is what I hope we'll learn more about this morning and we are very pleased to have with us Ms. Fisher, who is the Assistant Administrator for Policy, Planning and Evaluation with the Environmental Protection Agency.

Ms. Linda Fisher.

STATEMENT OF LINDA J. FISHER, ASSISTANT ADMINISTRATOR, ENVIRONMENTAL PROTECTION AGENCY, ACCOMPANIED BY RICHARD MORGENSTERN, DIRECTOR, OFFICE OF POLICY ANALYSIS, AND DENNIS TIRPAK, DIRECTOR, STRATEGIC STUDIES, OFFICE OF POLICY ANALYSIS

Ms. Fisher. Thank you, Mr. Chairman.

I appreciate the opportunity to be here today to talk to you about our recent study on policy options to stabilize emissions of greenhouse gases.

I am accompanied today by Dr. Richard Morgenstern, the Director of the Office of Policy Analysis at EPA and also by Dr. Dennis

Tirpak, who will be helping out with the charts and contributed tremendously to this report.

As you might remember, in 1986 the Congress asked the then Administrator of EPA, Lee Thomas, to undertake a study of policy options that could be used to limit emissions of greenhouse gases. The draft of that study was available earlier this year and I want to lay out its contents for you today.

First, when the Agency began the report we established certain goals. The first was to define the nature of the problem and the causes. To do this EPA researched current trends in concentration of greenhouse gases and developed a global inventory of emissions sources. We then projected what might happen to these emissions given certain alternative economic assumptions.

Our charge was then to identify various policy options that could limit emissions of greenhouse gases and try to assess what difference they might make in terms of limiting ultimate warming.

Well, I believe that we responded fully to the congressional request. I think it is important for the Members of Congress to understand the limitations of the type of study that we have before you today.

First, given the nature of the problem and the timeframe, that is that we are looking at something that might occur over the next century, the assessments of economic growth and our assessments of technology development are going to be extremely uncertain.

Additionally, although we identified policy options we still have yet to do considerable analysis of the cost of implementing these options as well as analyzing what kind of implementation barriers we might have.

Finally, our simulations of both the global economic and climate systems, although state of the art, is very highly simplified and the members should keep that in mind as they review the information.

Before I get into the details of the report, let me take a few minutes to explain and define more clearly the problem and the contribution to the problem.

The first chart shows the greenhouse gases and their overall contribution to the warming problem. The most important greenhouse gas, as you probably know, is carbon dioxide, which contributes approximately 50 percent of global warming.

Sources of carbon dioxide in the atmosphere come largely from fossil fuel combustion, which comprises about 75 to 85 percent of CO_2 emissions, as well as deforestation.

Other gases include methane, which accounts for approximately 18 percent of the problem; chlorofluorocarbons [CFC's], which as you know are the subject of the Montreal protocol which make up between 14 and 18 percent of the problem; and nitrous oxide, which comprised about 6 percent of the problem.

The next chart takes a step away from the actual gases and looks at what kind of activities in the economy contribute to global warming. Energy use, as you can see, is the principal source of greenhouse gases, energy use, and production, that is, and it comprises 57 percent of the problem.

CFC's again, the manmade chemical, comprises 17 percent of the problem.

Various agricultural practices make up 14 percent of the problem.

Land use modifications such as deforestation contribute 9 percent to the problem.

The charts indicate I think most importantly that as we begin to analyze policy options we really have to look across all different economic sectors and evaluate what policy options might be most effective in those sectors.

The next chart focuses principally on CO_2 emissions that come from fossil fuel combustions and it looks at it in terms of a global perspective and as you can see, it is a trend line.

Although North America is a significant contributor of CO_2 from fossil fuel burning, it is important to note that our trend as well as that of Western Europe are actually on a decline. That is largely a result of the energy efficiencies that we gained over the past 15 years as a result of the fuel crisis.

Equally important on that chart to me is the fact that China, the People's Republic of China, and Eastern Europe, driven largely by the Soviet Union, are on increasing trends in terms of CO_2 emissions from fossil fuel use. Both of those countries have very aggressive economic development plans under way. Both of them are fuelled largely by coal, so as their economies increase we can anticipate that their contribution to CO_2 will also increase.

Now let me turn to the findings of the report.

I'll run through the four major findings quickly and then I'll want to talk about each one of them individually.

The first finding was that although there are large uncertainties, we know that if we continue business as usual, a rapid climatic change over the next century is possible.

The second finding was that there are policies and technological choices that we can make that will make a difference in terms of slowing the rate of warming worldwide.

The third finding was that if any action is going to be effective it cannot be unilateral. We must act on a global basis and we must engage both the developing countries as well as the developed countries.

Last, just as there are many countries and activities that are contributing to the problem, there is a wide range of policy options and technologies available to us to implement—to control the problem.

Looking at it another way, there is no quick fix or silver bullet that is going to answer the global warming problem.

Now let me go through each of these findings in a little bit more detail.

As I said, although the uncertainties are large, rapid climate change over the next century is possible.

The graph shows the amount of warming projected for the next century, somewhere between 2.5°C and 5.5°C between now and the year 2100.

The uncertainty is represented by the shaded area on the graph and it is due to different alternative economic assumptions that we use to make our projections.

The lower end of the range assumes a slower economic growth and incorporates assumptions that tend to minimize the impact of greenhouse gas concentrations on climate. The upper end does the converse.

The next chart indicates that policies and technologies can make a difference. Although our study, as I said, did not consider costs or implementation problems, it did identify a number of policy options that if implemented on a global scale can reduce the rate of warming.

Different policy options if combined together could limit global warming to roughly 1 to 2 percent by the year 2100 and if you look at the chart, the top half, the purple half, was the projected warming that we showed on the previous chart. The lower red portion indicates where the warming would be if you implemented a variety of policy options.

The third finding, as I said, was that no single country dominates the emissions of greenhouse gases. All countries contribute to the problem and virtually all countries must participate if we are to effectively deal with it.

Although the United States, as you can see from the chart, is the single largest contributor and contributes approximately 21 percent to the problem, there are other significant players in this action.

The European Community plus Japan make up an additional one-fifth of the problem and the Soviet Union and the Eastern bloc countries make up an additional 20 percent of the problem. Again, what is not reflected there is the fact that developing countries such as China can dramatically distort actions taken perhaps by the United States or the rest of the developed world as they grow.

The fourth finding, and I think the chart that got the most attention in our report, indicates that there are a wide variety of policies and technologies that are available to us as we make an attempt to address this problem.

I will touch on a couple of them here and perhaps address the others in questions.

The first one we looked at in terms of policy options was a full phaseout of CFC's. As I said earlier, the CFC reduction is the subject of the Montreal protocol. This anticipates a complete phaseout of CFC's by around the year 2000.

Another policy option that people talk about frequently is reforestation. Our study analyzed the effect that would result from a dramatically increased reforestation effort and a complete halt of deforestation by the year 2025. We also looked at improved transportation efficiencies, looking not only at the automobile but also at truck, air, and rail efficiencies as well.

In terms of other energy efficiency we analyzed the impact that we might appreciate from increased energy improvements in the residential sector, commercial sectors, and industrial sectors of the economy.

It is important for the committee to realize that although a significant step, this study is only a first step in terms of policy work that needs to be done. In the short term we are in the process of getting feedback from our own Agency Science Advisory Board on the contents of the report. Additionally we have put it in interagency review so the rest of the Agencies of the Federal Government can give us their feedback on it.

In the meantime, we need to do additional work, as you have pointed out to the Agency, in the way of cost analysis on the different policy options. We also have work underway to look at implementation problems with each of these policy options.

We are also going to continue to participate in the Federal Research Program. Specifically we need to do a lot more work on the role that oceans and clouds are going to play in ultimate climate change as well as biological and other feedback systems.

We are going to continue our aggressive work in the Intergovernmental Program on Climate Change [IPCC], which is the panel that was organized under the United Nations Environment Programme [UNEP] to coordinate international activities on global climate change.

Let me point out for you that the United States is chairing the most important of those work groups, which is the international work group to look at response policy options, options similar to what we have laid out here in our report.

Finally, the EPA intends to use the work of this report as well as this additional analysis that we currently have underway to contribute to the administration effort to pull together a policy response to climate.

This summarizes pretty much the major findings of our report and I'd be glad to answer any questions you or the other members of the committee might have.

[Testimony resumes on p. 143.]

[The prepared statement and charts of Ms. Fisher follow:]

TESTIMONY OF
LINDA J. FISHER
ASSISTANT ADMINISTRATOR
U.S. ENVIRONMENTAL PROTECTION AGENCY
BEFORE THE
SUBCOMMITTEE ON ENERGY AND POWER
OF THE
COMMITTEE ON ENERGY AND COMMERCE
UNITED STATES HOUSE OF REPRESENTATIVES

MAY 4, 1989

Mr. Chairman and Members of the Subcommittee, I am very pleased to be given this opportunity to discuss with you the Environmental Protection Agency's Global Climate Change program and its draft report entitled, "Policy Options for Stabilizing Global Climate."

Policy Options for Stabilizing Global Climate

CONGRESSIONAL REQUEST FOR REPORTS ON GLOBAL CLIMATE CHANGE

In 1986, the Senate Committee on Environment and Public Works Subcommittee on Environmental Protection requested that EPA develop two reports on global warming. One report was to focus on "Policy options that if implemented would stabilize current levels of greenhouse gas concentrations." The second report was to examine "The potential health and environmental effects of climate change including, but not be limited to the potential impacts on agricultural, forests, wetlands, human health, rivers, lakes, estuaries as well as societal impacts."

In response to the Congressional Directive, EPA prepared a draft report entitled, Policy Options for Stabilizing Global

Climate that I will discuss today. This report investigates technological and policy options for stabilizing and reducing greenhouse gas emissions.

The draft EPA Report is a first attempt to comprehensively analyze alternative policy options to limit greenhouse gas emissions on a global basis. This study has been conducted over the past two years and has been a major undertaking for us. I am quite pleased with the product. At the same time, I must caution the Committee and the public at large, that this is, in fact, a draft study. The Agency's Science Advisory Board reviewed the draft report at a meeting on April 4-6, and we are awaiting their final comments. The report is also currently undergoing an interagency and peer review.

THE STABILIZATION REPORT

This report is the result of a major two-year study of the policy options available to stabilize current levels of atmospheric greenhouse gas concentrations. The study produced a comprehensive summary of estimated greenhouse gas sources and trends in concentrations. The major sectors contributing to emissions (energy, industry, agriculture, and forestry) and the major greenhouse gases (CO_2, CH_4, N_2O, and CFCs) are considered on a global basis. The study examines various domestic and international policy options that, if implemented, could slow the buildup of greenhouse gases which may contribute to global climate change. These policy options include the phasing out of CFCs, halting deforestation and initiating reforestation, increasing use of natural gas, increasing energy efficiency in transportation, buildings, and industry, and developing non-fossil fuel technology.

The primary focus of this report is to identify policy options that appear promising. The report has not made a detailed assessment of the costs and other economic aspects of these options. It was impractical to complete such an assessment in this report. However, we view cost and other economic considerations to be of major importance. In subsequent studies, we plan to make detailed assessments of economic impact and implementation costs of various policy options.

As part of an international effort, options must reconcile the requirements for both sustainable economic development and a safe environment. Therefore, they should be as cost-effective as possible. The report also suggests future research activities that would improve our understanding of the sources of greenhouse gases and areas where technological improvements would reduce the emission of these gases.

Sources of Greenhouse Gases

Many diverse sources have contributed to the increase in greenhouse gas concentrations, including the burning of fossil fuels, deforestation, and, over the past 40 years, the use of synthetically produced chloroflourocarbons (CFCs). CO_2 is currently the most significant greenhouse gas, responsible for about half of our current increases in our commitment to estimated future warming, but many other gases contribute to global warming--CFCs, methane (CH_4), and nitrous oxide (N_2O).

All greenhouse gases have multiple sources. The primary anthropogenic sources of CO_2 are fossil fuel combustion and deforestation. Scientists currently estimate that approximately three-quarters of CO_2 emissions from anthropogenic sources come from the burning of fossil fuels, and one-quarter results from deforestation--largely in tropical countries. Major methane sources are rice production, enteric fermentation in domestic animals, biomass burning, fossil fuel production, and anaerobic decomposition in landfills. Major N_2O sources are nitrogenous fertilizer use, land clearing, biomass burning, and fossil fuel combustion.

Greenhouse gases are emitted in both the developed and less developed countries. Western Europe and North America account for approximately forty percent of fossil fuel emissions, but since the early 1970s, their emissions have remained relatively stable. In fact, the United States' fraction has been decreasing. The Soviet Union and eastern Europe, the People's Republic of China, Pacific rim countries, and developing countries contribute approximately sixty percent of fossil fuel emissions. And, most importantly, their share is rising. With regard to other greenhouse gases, approximately three-quarters of the CFCs are produced in North America and Europe, while major anthropogenic sources of methane are associated with rice production in Asia. Thus, all countries contribute to greenhouse gas emissions and share some responsibility for their continuing growth.

Study Design

EPA established several program goals in developing the "Stabilization Report": (1) assemble data on global trends in emissions and concentrations of greenhouse gases; (2) develop an integrated analytical framework to study how economic, policy, and scientific assumptions influence warming estimates; (3) identify promising technologies and practices that have the potential to limit greenhouse gas emissions; and (4) identify policy options that could slow the buildup of greenhouse gases which may contribute to climate change. To achieve these goals, EPA conducted an extensive literature review and data gathering process. The Agency held several informal panel meetings and enlisted the help of leading experts in the governmental, non-governmental, and academic research communities. EPA also conducted five workshops to gather information and ideas regarding factors affecting atmospheric composition and options related to greenhouse gas emissions from agriculture and land-use change, electric utilities, end-uses of energy, and developing countries. Experts from NASA, the Department of

Energy and the Department of Agriculture were consulted.

Based on the results of this process, EPA developed an integrated analytical framework to organize the data and assumptions required to estimate (1) emissions of radiatively and chemically active gases; (2) concentrations of greenhouse gases; and (3) changes in global temperatures. The framework, though highly simplified, permits alternative assumptions to be made concerning population growth, economic growth, technological change, and emissions reduction strategies.

In developing our report, we recognize that many factors will influence future greenhouse gas emissions, including rate of population growth, economic growth, technological change, fuel mix, and energy, industrial, and agricultural policies. To broadly account for these factors, EPA developed four scenarios of possible future worlds for analysis. Two scenarios assume that no policies are adopted to reduce the emission of greenhouse gases--one assumes that future economic growth and technological change are rapid (Rapidly Changing World or RCW) and one assumes economic growth and technological change are slow (Slowly Changing World or SCW). Both of these scenarios have analogous counterparts which assume that stabilizing policies are adopted (RCWP and SCWP).

Limitations and Uncertainties

This analytical framework models some of the major processes that will influence the rate and magnitude of greenhouse gas accumulation during the next century within a structure that is suitable for policy analysis. There are, however, a number of major limitations to this framework. First, assumptions are made in the framework about rates of economic growth and technological change, which strongly influence forecasts of future greenhouse gas emissions. But economic growth and technological change are difficult to forecast. Second, detailed economic and cost analyses were not conducted. We did not attempt to calculate the macroeconomic impacts of policy options or the total costs associated with various strategies. However, promising technologies were qualitatively screened based on judgments of their expected cost-effectiveness. Third, limitations on capital investment were not explicitly considered. Fourth, economic feedbacks are not fully represented. Finally, our attempts to depict the ocean, changes in atmospheric chemistry, and biogeochemical feedbacks are highly simplified. In summary, we attempt to present our results with all of the uncertainties about the economic system and physical climate system fully recognized.

GENERAL CONCLUSIONS

Uncertainties regarding the magnitude and timing of climatic change are large, but there is a growing consensus in the scientific community that global warming, perhaps of significant degree, due to anthropogenic emissions of greenhouse gases is probable, and rapid climatic change over the next century is possible. Within EPA's scenarios, if no policies to limit the emission of greenhouse gases are undertaken, the equivalent of a doubling of CO_2 is estimated to occur between 2030 and 2040, and the earth warms by 2-6 degrees Celsius by the end of the 21st century.

Very large reductions in anthropogenic emissions would be necessary to stabilize atmospheric concentrations of greenhouse gases. EPA's scenarios do not achieve these reductions, but rather examine a mix of policy responses to limit emissions of greenhouse gases that could significantly reduce the estimated rate and magnitude of climate warming.

Policy and technological measures to limit greenhouse gas emissions are estimated to decrease the magnitude and speed of projected global warming, regardless of uncertainties about the response of the climate system. With such global policy measures, the report estimates that the rate of global warming could be significantly limited over the next century, perhaps by one half or more of the warming that is estimated to occur without policy intervention.

Global cooperation will be essential to effectively reduce greenhouse gas emissions. No single country or source will contribute more than a fraction of the greenhouse gases that may contribute to global climate change. Any overall solution to the climate change problem will require cooperation of many countries and reductions in many sources. For example, postponement of action by developing countries to reduce greenhouse gas emissions would severely hamper the effectiveness of any reduction by developed countries.

The report considers a wide range of potential policy options to reduce greenhouse gas emissions. Although detailed economic analysis was not conducted, we believe that some emissions reductions are possible while promoting economic development, environmental, and social goals. In industrialized countries, acid rain, urban ozone, and dependence on imported energy could be reduced as part of an overall strategy that reduces greenhouse gas emissions. Energy efficiency improvements are important all over the world. In some developing countries efficiency improvements may actually reduce capital requirements in the power sector and encourage long term economic development. Carefully designed efforts to halt deforestation in developing countries could possibly provide long-run economic and environmental benefits, in addition to reducing the emission of greenhouse gases.

Technological and Policy Options

Various technological and policy options were evaluated for their estimated effectiveness in reducing the projected rate and magnitude of global warming. No single technology or policy can have a significant impact in mitigating the accumulation of greenhouse gases because of the wide variety of sources. But, the models predict that many individual measures, each having a modest impact on greenhouse gas emissions, can have a significant impact on the estimated rate of climate change when combined. The model results imply that only by aggregating the effects of many technical opportunities over a long time can significant reductions in greenhouse gas emissions be achieved. This implies that any overall strategy to reduce greenhouse gas emissions must seek the right combination of pricing, regulation, technological development, procurement, state programs, and information transfer.

Let me speak about a few of these options. Although we have not conducted detailed economic estimates, there is an extensive literature indicating that improvements in end-use energy efficiency provide the best option for reducing CO_2 emissions over the next few decades. Reductions in energy use would also reduce emissions of CH_4, N_2O, NO_x, and CO. Many efficiency improvements are possible by the year 2000. These include improvements in the transportation sector and accelerated improvements in building shells, lighting, space conditioning, and appliances. All of these could significantly reduce energy requirements.

Near-term reductions in greenhouse gas emissions from electricity generation are possible through both efficiency improvements and fuel switching. Improved fossil fuel electricity generation technology, such as advanced combustion turbines and cogeneration, can increase the efficiency of using these fuels by up to 25 percent. Also, the use of more natural gas to displace coal as a fuel for generating electricity could reduce CO_2 emissions by a substantial amount in the near term.

Alternative fuels, such as hydroelectric, biomass, solar, geothermal, wind, and nuclear, do not emit significant amounts of greenhouse gases and could make an important contribution to reducing these emissions in the medium term and could virtually eliminate many categories of emissions over the long term. For widespread use of alternative fuels, important engineering, economic, environmental, and social issues must be resolved.

Reforestation may offer one of the most attractive options for reducing net CO_2 emissions. Preliminary estimates of the feasibility of large-scale reforestation suggest that with aggressive reforestation programs, the current deforestation trend could be reversed and that a significant net increase in forest biomass is possible.

Improvements in agricultural production efficiency could reduce emissions from those sources. Increasing the efficiency of fertilizer use, productivity of livestock systems, and productivity of rice cultivation could decrease the emission of greenhouse gases per unit of agricultural product. Also, reducing the amount of biomass burning associated with agriculture through sustainable agriculture and effective utilization of crop residues would reduce the emission of greenhouse gases.

According to our current estimates, a phase out of CFCs could reduce the amount of global warming by as much as 15 percent.

Research Needs

The Report defines the major uncertainties relating to climate change and indicates research needs to both resolve these uncertainties and reduce greenhouse gas emissions. The Administration is moving ahead to expand research in this area. The President's Budget requested increased resources for a directed and coordinated global change research program. The report suggests that future research activities focus on the characterization of sources of greenhouse gases, climate system feedback analysis, and development of improved ocean circulation models. In addition, research and development is needed to improve our options for limiting greenhouse gas emissions. There is a need for the development of new technologies in the areas of CFC substitutes, energy efficiency (including lighting, industrial processes, vehicles, and insulating materials), alternative fuels (biomass, solar, nuclear, hydrogen, and energy storage techniques), agricultural practices (livestock management, rice production, and biomass burning), and forest management.

GLOBAL CLIMATE CHANGE AND EPA

National Activities

EPA, along with other Federal agencies, intends to continue to be an active participant in the formulation of a Federal research agenda, in the conduct of research that improves our understanding of the earth's climate system and that supports the needs of policymakers, and in future debates over strategies to adapt to climate change or to limit emissions.

The development of a national policy, as mandated under the Climate Protection Act, will be complex and the formulation of a coordinated international response may take a great deal of effort. Much work remains to be done by the research community to understand emissions, the interactions of emissions with the biosphere, and the ultimate effect on man and the environment of increasing greenhouse gas emissions levels in the atmosphere. At EPA, we intend to examine the prudent steps that can be undertaken to achieve multiple goals, and do so in a timely manner. In the future, we will do a great deal more to examine the cost of different options and the technological, cultural, and political barriers to implementation of policies.

International Activities

As more countries recognize that no single nation acting alone can decisively affect the greenhouse gas problem, international organizations have increasingly become involved in the climate change arena. These include the United Nations Environment Programme (UNEP), the World Meteorological Organization (WMO), and the International Council of Scientific Unions (ICSU). The most significant recent event has been the establishment by WMO and UNEP of the Intergovernmental Panel on Climate Change (IPCC).

The first meeting of the IPCC was held in November 1988, with over 30 countries participating. The IPCC established three working groups to (1) assess available scientific information on climate change; (2) assess the possible environmental and socio-economic impacts of climate change; and (3) formulate possible response strategies. The working group on science is chaired by the United Kingdom. The working group on impacts is chaired by the Soviet Union. And, the United States chairs the working group on response strategies.

In late January 1989, the United States hosted the first meeting of Working Group III. The meeting was introduced by Secretary of State James A. Baker III, who made four points: first, that we can probably not afford to wait to resolve all uncertainties before acting; second, that we should focus immediately on steps which are justified for other reasons, including reduction of CFC emissions, greater energy efficiency, and reforestation; third, that global solutions should be as specific and cost-effective as possible; and fourth, that solutions must reconcile the requirements for both economic development and a safe environment. The three day session ended with the adoption of an ambitious work plan. The plan includes the development of adaptive and emission limiting responses for agriculture, industry, natural resources, and coastal zones. The EPA was an active participant in this entire process along with other agencies. The Agency expects to play a very active role in the IPCC process in the future. EPA looks forward to working with interested federal agencies, and others, and to the exchange of research and policy findings with other countries.

US Environmental Protection Agency

GOALS FOR THE STABILIZATION REPORT

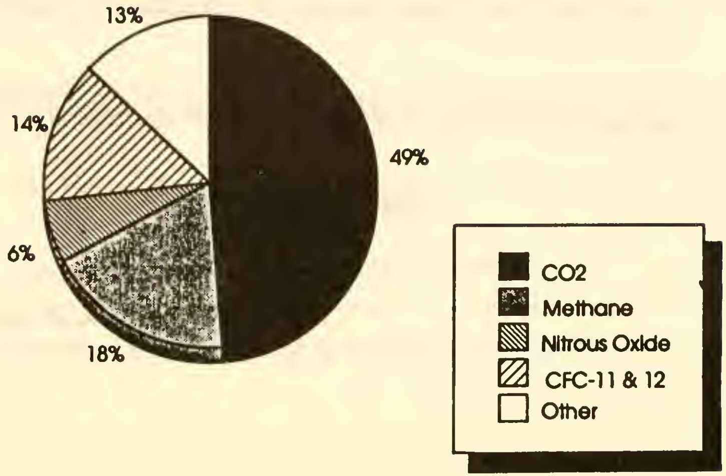
- Define the Nature of the Problem and its Causes
- Assess Future Trends in Global Emissions
- Identify Emission-Limiting Policies and Technologies

LIMITATIONS

- Economic Growth and Technological Change are Difficult to Predict
- Detailed Cost Analyses of Policies Were Not Conducted
- Models of the Global Economy, Oceans and Climate are Highly Simplified

US Environmental Protection Agency

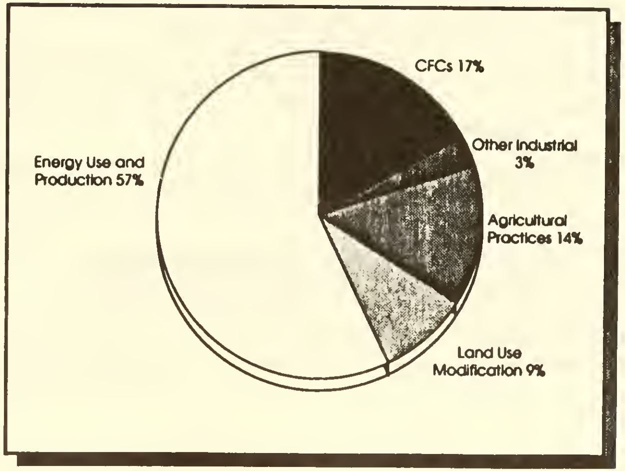
Greenhouse Gas Contributions to Global Warming



Source: Hansen et al.

US Environmental Protection Agency

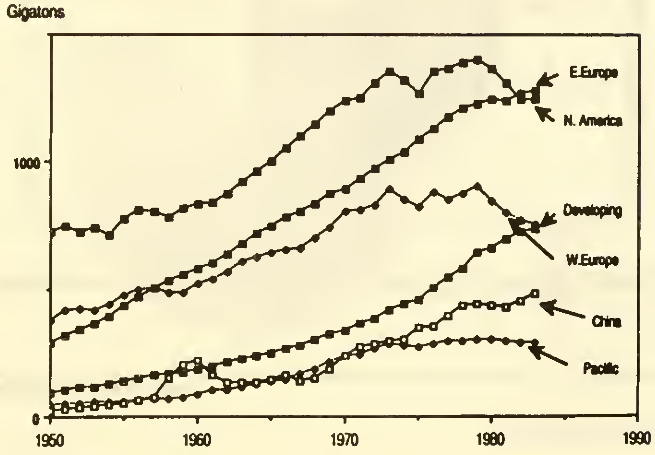
Sources Contributing to Global Warming



Estimates based on allocation of emissions.

US Environmental Protection Agency

Annual Fossil Fuel CO2 Emissions by World Region 1950-1985



Source: R.Roty, 1987

MAJOR FINDINGS

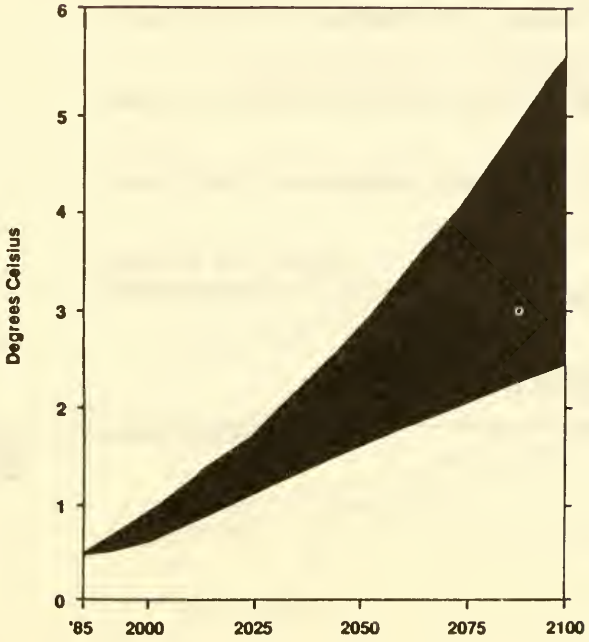
- Uncertainties are Large, but Rapid Climatic Change Over the Next Century Is Possible.

- Policy and Technologies Can Make a Difference.

- Effective Action Involves the Cooperation of Many Countries.

- A Wide Menu of Policies and Technologies Is Available.

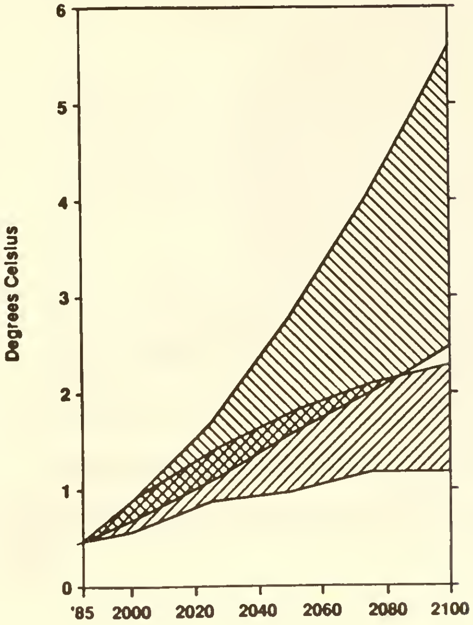
U.S. Environmental Protection Agency



Uncertainties are large, but rapid climatic change over the next century is possible.

Realized Warming:
No Response Scenarios
(2 - 4 Degree Climate Sensitivity)

U.S. Environmental Protection Agency

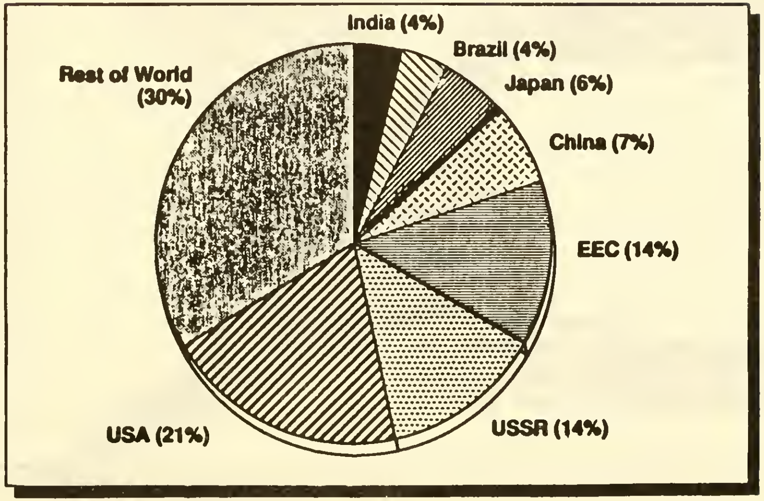


Policies and technologies to limit greenhouse gas emissions could decrease the magnitude and speed of global warming.

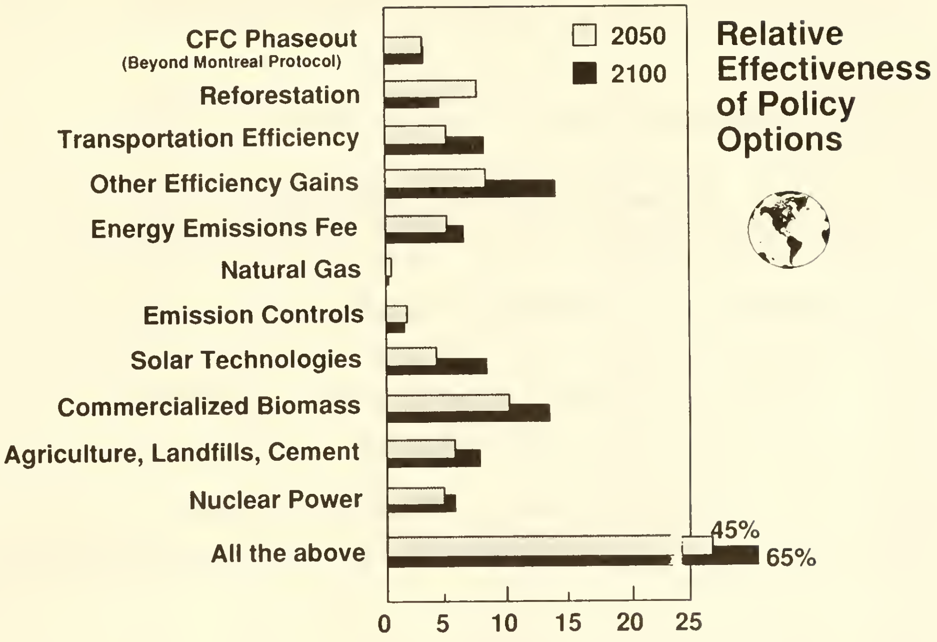
Realized Warming: No Response and Stabilizing Policy Scenarios
(2 - 4 Degree Climate Sensitivity)

U.S. Environmental Protection Agency

Effective Action Involves the Cooperation of Many Countries



SOURCES: EPA (1988), Tirpak (1986), United Nations (1987), US Bureau of Mines (1985), IRRI (1986), FAO (1987,1988), Bolle, et al. (1986), Rotty (1987), Lerner, et al. (1987), Seiler (1984), WMO (1985)



Relative Effectiveness of Policy Options

EPA'S STUDY IS A FIRST STEP...

ADDITIONAL WORK REMAINS TO BE DONE

- Obtain Feedback on Our Report from SAB and Others
- Assess Technologies/Costs and Investment Strategies
- Analyze Domestic and International Implementation Options (Market/Regulatory/Political/Cultural Barriers)
- Conduct Research on Oceans, Clouds, Biological, and Climate Feedbacks
- Utilize Intergovernmental Panel on Climate Change (IPCC) to Develop International Understanding
- Develop National Policy as Required by the Climate Protection Act

Mr. **Sharp**. Let me first get a little clearer picture of what you covered in your concluding remarks, where we are and where we expect to be in terms of ability to make policy. At this point, what you've provided us is not recommendations obviously but simply analysis of possibilities; is that correct?

Ms. **Fisher**. That's correct.

Mr. **Sharp**. That's correct and are we to expect at a future point, recommendations as to policy possibilities from the administration, from EPA?

Ms. **Fisher**. Well, you're very correct in stating that this was a report to analyze a variety of policy options that could be taken over time to address the emissions of greenhouse gases. There's a lot of work that would need to be done before I think we'd be ready to make a specific—either one policy recommendation or a series of them.

Those would include far more detailed analysis on the cost implications of each of these policies, more work on the technological feasibility and the timeframe that different policy options could actually be implemented in this country as well as other countries.

We need to do some more work on the tradeoffs of the different policy options as they play off against each other.

In terms of timeframe, the administration doesn't have a deadline by which they're trying to develop a single policy response but we are very actively involved in the intergovernmental process. As I said earlier, the United States is chairing the work group on response policies. That is important because that work group is to develop a report in the fall of 1990 that will target a variety of policy options that could be implemented worldwide to deal with global warming.

I don't think I would go as far as to say that there will be an intergovernmental recommendation—in other words, an international recommendation but a lot more work will be done on what can be done and how it could be implemented throughout the world. The United States is trying to time our domestic activities to be in complete sync with the international activities so I think we'd be looking to something next year before we really got into anything more specific in terms of real policy responses.

In the meantime, as we at the Agency begin to think through environmental policies that we are currently implementing, perhaps most specifically as the administration starts looking at the Clean Air Act, we are keeping in mind the implications of the alternatives that we review would have on global warming, what effect different policy options would have on emissions of CO_2 or on energy efficiency.

So, we've started to inculcate greenhouse concerns into our current analysis as we implement other environmental programs.

Mr. **Sharp**. It seems to me that's extremely important because to get international or even national comprehensive policies is going to be highly complicated both intellectually and politically both here at home and abroad, but it seems to me that we want to begin clearly taking steps that we have knowledge about, or when we're making decisions understand what their implications are and whether they add to or reduce our impact on global climate.

It seems to me that was the basic thrust of the National Academy of Sciences' recommendations to President Bush—to start taking prudent steps. If we don't know for sure the cause, if we don't know for sure the outcomes, we nonetheless can start taking actions that will help us along that path even if we're not ready to make final decisions and I trust that's what the administration will attempt to do when it's involved in its clean air legislation that—you anticipate that will be sent up this May—I mean this month, still?

Ms. FISHER. We are still pushing for an end of the month deadline.

Mr. SHARP. End of the month deadline. That's before Memorial Day. Let me ask you this though. In terms of the international situation and I realize this is not just an EPA decision, this is broader in the administration but you folks are a critical part of that.

I guess many of us want to make sure the United States is not just waiting for the international community to come to some kind of conclusion but is in fact leading the international community to reach conclusions and to take coordinated actions. You mentioned we are chairing the working group. I hope we're pressing the working group.

Ms. FISHER. We are. In fact our study is probably going to be one of the most important contributions to the work of that work group. We have shared it with the other countries. Additionally, we have been very active in all the aspects that the work group has underway.

It's a work group made up of about 17 other countries. My feeling is we've been very aggressive in leading them and in being sure that the work that people projected to do is in fact underway. In fact a group of us are going to go to Geneva next week to meet with the heads of delegations of all the countries to see what they have been doing in terms of contributing to the policy analysis.

Mr. SHARP. Is the United States in any other way communicating with the Soviet Union and with China with respect to their future energy policies and what technologies are available and what not? We have no way to dictate the outcome of their policies but nonetheless, are we engaging them in any other way than through this working group that you're aware of?

Ms. FISHER. The Soviet Union is on the work group and has been contributing to it. Additionally, the intergovernmental panel is divided up into three work groups. One is the response strategies work group that we chair. A second work group is focusing on effects, the effects on society of increases in climate change and the Soviet Union is the cochair of that work group. So they have been participating in that.

Additionally, we have a bilateral agreement with the Soviet Union that among other things addresses climate change and we will be engaging them through that bilateral to be sure that they are looking at their own energy systems and their own economic growth projections to see what we can do to have them take climate change into account.

In fairness to them, they seem to have a lot of other problems in their government right now and I'm not positive that this is No.1

on the plate but in terms of their environmental ministry, they have been very interested and actively engaged in the issue.

Mr. **Sharp**. Well, you exhibit what is clear realism about the problem but it only heightens the necessity for our government and other governments to raise these on the international agenda at all kinds of conferences and all kinds of forums because it's precisely to get other governments—our own government has trouble keeping this anywhere on its plate—and if it's not continually raised by spokesmen of the United States and others I think it's going to be very hard for China and the Soviet Union, and the developing world, to take it seriously.

I don't mean to suggest—I'm just trying to say what we must do. What they must do are going to be extraordinary things as well and it seems to me that it behooves us to make that a central part of our foreign policy that we are raising environmental issues both in terms of how we act on our own issues as well as trying to work out agreements with others because it simply is not going to happen without enormous pressure from all sorts of folks, in their countries, in our country and elsewhere.

Ms. **Fisher**. We also have a bilateral with the Peoples' Republic of China dealing specifically with climate change and for the same reason, we're trying to get them to take a look at their emission sources and their energy projections. Additionally, yesterday and in fact ongoing today, the Administrator of EPA was meeting with the head of the Ministry of Environment in Japan and climate change was a big part of their agenda and they spent some time in a private meeting talking about what Japan can do to increase participation of the Pacific Rim countries and include China in that in the whole international debate.

So it's something that comes up when the Administrator meets with foreign leaders. It's also something that the President is becoming more and more aware of and is bringing up in his different meetings with various Prime Ministers.

Mr. **Sharp**. Well, I hope you folks within the administration would be continually raising it with the White House and State Department that every time the Secretary of State meets, every time the President meets, every time the Vice President attends a funeral, that they raise these questions. That's when change comes sometimes. So the point is, you help remind our leaders and we have to remind ourselves in Congress to keep these on the agenda.

Let me recognize our ranking Republican, Mr. Moorhead.

Mr. **Moorhead**. Thank you. One of the issues that we're concerned with on this committee is of course nuclear power. I see that this is one of the options that's listed for stabilizing global climate, to increase the availability of nuclear power and one of the things you speak about—you say advance designs, in particular the modular high temperature gas cooled reactor have been proposed to attempt to overcome some of the problems that the nuclear industry has.

That's one of the issues that we're dealing with and I'm glad to see that you've included that in your report. Are you hopeful that we can increase with safety that particular option?

Ms. **Fisher**. Congressman, the report anticipates an increase in nuclear power worldwide. In our country as you know, we do have some problems in terms of its acceptance for a variety of reasons.

We think that as people look across their energy options and look to energy sources that do not contribute greenhouse gases to the atmosphere, you do have to take a hard look at nuclear power. That is not to suggest that in the course of the study we found any of the answers to the problems that we're having in the United States.

It more speaks to the fact that it does not contribute greenhouse gases and it's a source of power that in fact people may need to look at more in the future.

Mr. **Moorhead**. Considering the political atmosphere around the world and the willingness of some countries to do more than others obviously in taking care of environmental problems, with your list of relative effectiveness of policy options that you have here, you have a number of things that are projected.

Have you made any estimates about the possibilities of reaching some of these goals through cooperation with other countries? Are you pretty optimistic that this can be done?

Ms. **Fisher**. In the intergovernmental process where the United States has been participating with other countries of the world, we have put on the table one of the big issues that we need to concentrate on is how in fact we would implement these or other policy options throughout the world. What would be the most effective way in different countries given different political systems, different economic systems, different energy bases, to implement policies that would reduce greenhouse gases.

My own sense is that there is not going to be a prescribed menu that each country will have to follow because each country has a different mix of sources and each country is going to have to figure out different ways to incorporate emission reduction strategies into their own society.

The intergovernmental panel is going to look at as part of its process some of the barriers to implementation, whether they are political or cultural or social or economic and try to come up with solutions to those barriers or ways to get around those barriers.

Am I optimistic about it? I am thus far because we have had tremendous interest and cooperation among many governments around the world, both developed and developing and from Africa and South America and Asia and all around the world. So people are participating which tells me they're taking it seriously.

They seem to be realistic about the problems that each country is going to face in terms of trying to implement policy options but they seem willing to discuss those problems. We haven't yet come up with the true test. We haven't come up with policy options that people have had to fight over or to debate yet. So we haven't had to put the hard question to people.

Pausing for a moment and looking to the Montreal protocol where the international community acted together to address a problem, that problem being CFC emissions, that gives me some hope that in fact people can come together, can agree on solutions and proceed to implement them in their own country.

So at this point, I am optimistic and it's because of the spirit and attitude that all the different governments have brought into the intergovernmental process.

Mr. **Moorhead**. One of the big things that we are being inundated with in the United States is trash, junk of all kinds. I notice one of the things that you have listed here is agricultural landfills and cement. Landfills are very unpopular when you want to put one in somebody else's area. Is this a prospect that you look to being increased for the future?

Ms. **Fisher**. No. The point was there was that landfills contribute methane, and methane is one the greenhouse gases. So, one of the policy options to deal with reducing methane is to control emissions of methane from landfills, and we are looking at technologies that can collect methane, some of which are already in place in different landfills in the United States. So, the issue is how to control emissions that are occurring from landfills, that being mostly methane but also some CO_2, and improving our technologies and implementing those technologies at different landfills. That is the issue there.

Additionally, one of the policy options people can encourage is recycling, which would reduce the amount of trash going into landfills and, therefore, reduce the amount of methane. So, it is not an interest in more landfills. It is an interest in improving the quality of the landfills that we have in terms of control devices on methane emissions and, perhaps, reducing them.

Mr. **Moorhead**. There is a study that is being made by some people that go and dig up these landfills after 20 years or so, and it shows that the newspapers that were dumped in there 20 years before are still readable. They do not change. They are still the same, and something maybe is going to have be done with these items that could be done away with in some other manner so that they do not just sit there and affect the atmosphere from their graves.

Ms. **Fisher**. That is the role that recycling can help play.

Mr. **Sharp**. The gentleman from Utah, Mr. Nielson.

Mr. **Nielson**. Thank you, Mr. Chairman.

Ms. Fisher, this is just a draft report, so far, isn't it?

Ms. **Fisher**. That is correct.

Mr. **Nielson**. And who is going to review it? Is DOE going to be able to review it before it is made final?

Ms. **Fisher**. Absolutely. In fact, they are reviewing it now. They were also involved in many of the workshops that led up to the actual draft that you see before you, and they will be and are currently participating not only in a review of this but in additional work that we have underway.

Mr. **Nielson**. When they review this report, suppose they do not think your assumptions are realistic, what then?

Ms. **Fisher**. Then, we will have, as we so often have with DOE, a big debate, and I am not positive how it will be resolved. Since they participated in the workshops early on that led to the final report, they have had input into a lot of the assumptions that we used. That is not to say that they agree with everything, but many of their concerns we think we have addressed.

Mr. Nielson. On page 29 of the executive summary, you state "Policies to promote energy efficiencies in all sectors succeed in substantially reducing energy demand". In other words, that is how we will solve it. What policies are you referring to, how much energy savings are you referring to, and how realistic is it that we will get those savings?

Ms. Fisher. We looked across all sectors of the economy in terms of transportation, the industrial sector, commercial sector—residential, commercial, industrial, and transportation sectors, and we tried to estimate what kind of energy efficiencies would be available over the next—or the time period in the report, and I can list those for you.

Mr. Nielson. Do you tie down the policy and the savings attached to that policy anywhere in your report, and if not, would you be able to provide that for the committee?

Ms. Fisher. The chart——

Mr. Nielson. I saw the chart, but I did not see——

Ms. Fisher. The chart tries to indicate for you what kind of savings you could get in terms of reduced warming scenarios by implementing each of those in the broad sense. We do not have—I do not believe we did a specific analysis of what energy efficiencies in the residential sector alone would give you. We combined them together.

Mr. Nielson. Let me ask you about the ambitious Energy Efficiency Program. They maintain that if we follow conservation policies, this sort of thing, we can have a lot more population and still not use any more energy. Do you think that's realistic?

Ms. Fisher. I am not positive I exactly follow your question, but I think that we think it is realistic to get serious energy gain.

Mr. Nielson. They say specifically they could keep world energy demand flat at the same time they have economic growth and population increases.

Ms. Fisher. We think that you can do that. If you get your energy efficiencies, then you can still enjoy economic growth or population growth and keep your energy increase flat.

Mr. Nielson. How does that tie with the World Energy Conference, which says it could double and triple, even without population growth?

Ms. Fisher. You can double and triple your energy use?

Mr. Nielson. Yes.

Ms. Fisher. Because I assume they have not taken into account improvements in energy efficiency, which is what we are saying you would need to do.

Mr. Nielson. So, you have two prestigious groups: One is saying we can increase the population and keep the energy constant; the others say we can keep the population constant but double our energy. There seem to be opposite contentions.

Ms. Fisher. I think what we are trying to say is that if you have—if our government and other government institute policies that will bring about energy efficiency, you will, in fact, reduce the use of energy over time, or if your population increases, you could keep your energy use flat, even though you have increased population.

Mr. NIELSON. Congressman Moorhead asked about how realistic your assumptions are on landfills and on nuclear. What about solar? We have been working on solar energy for a long, long time. Can we really achieve the efficiencies you are talking about there, and if so, when?

Ms. FISHER. We tried to include in the report, and I will let Dr. Morgenstern address this more fully, realistic assumptions about what kind of technologies can be brought online. In other words, we did not try to use in the report things that we thought were completely out of the realm of possibility. We tried to put on the plate realistic policy options that people can look at. We are doing more work in terms of cost analysis, technological analysis, and implementation problems to find more precisely over what time period some of these technologies could be brought online.

Mr. NIELSON. One that particularly bothers me about solar is you claim that by 2025 solar technology will be available to make the cost 4.6 cents a kilowatt hour.

Mr. MORGENSTERN. That is the assumption that was used by the Department of Energy, actually. We sort of adopted their long-term assumption for the year 2000.

Mr. NIELSON. I was just going to ask have they checked that assumption?

Mr. MORGENSTERN. Well, it is their exact assumption.

Mr. NIELSON. I see. Okay. Thank you.

Mr. MORGENSTERN. I would just like to comment on an earlier point in terms of the energy demand. In our work, we did not assume that energy demand was actually declining. What we assumed was that energy was being provided by different sources which did not produce as much greenhouse gases. So, for example, solar, some of the biomass, essentially enables you to have your energy levels without releasing as much greenhouse gases.

Mr. NIELSON. Thank you.

Mr. Chairman.

Mr. SHARP. I thank the gentleman.

The gentleman from Florida is recognized.

Mr. BILIRAKIS. Thank you, Mr. Chairman.

Ms. Fisher, is China a member of the working group?

Ms. FISHER. Yes, sir. In fact, they are a vice chair to us on the response strategy work group.

Mr. BILIRAKIS. And you have already mentioned, I think, a couple of the developing countries. Would we say that, for the most part, the developing countries are well represented in the working group?

Ms. FISHER. I would say they are represented. To be very honest with you, we are a little concerned that they increase their participation. As you can guess, they have a funding. Participating in the meetings is expensive, finding the experts is expensive, and for many of their countries, they do not have—they are not real deep in terms of technical expertise. It is a concern not of the United States but the other developed countries, and in fact, we have a kind of subwork group to look at ways to even more engage the developing countries.

Mr. BILIRAKIS. We cannot belittle the significance of the problem, of the issue, there is no question about that, but realistically, are we expecting developing countries and China—I do not know that we would put China in that category, but God knows, it is developing—would we realistically expect those people to—well, for instance, we see the line, and it is going up in so far as CO_2 omissions are concerned. We see the line going up as far as developing countries and as far as China, and those lines are up through 1985, apparently, according to your charts. Have we received statistics? Is that line—is that curve continuing to go up for the years 1986 and 1987?

Ms. FISHER. Dennis, do you know?

Mr. TIRPAK. I think that it is going up—has gone up in the last 2 years.

Mr. BILIRAKIS. It has gone up for developing countries and for China?

Mr. TIRPAK. We would expect, probably, that that would continue for the immediate future, given what we know about China's plans for coal use and plans for use of coal also in India, another of the developing countries.

Mr. BILIRAKIS. Well, that is the whole point, I guess. I mean, realistically, would we expect these countries that are really developing and "progressing"—and I will use that term in quotes, because progress also means problems in these areas—would we expect them to interrupt that "progress"—again, using that term in that sense—and that development by cooperating with the rest of the world? I mean it is an awful lot easier for the United States of America, which is, so to speak, already developed, to be able to make these changes, many of them drastic changes in terms of the way that they live. I mean have we considered all that, or are we just really harping into the wind when it comes to anticipating that kind of worldwide cooperation?

Mr. TIRPAK. With respect to China, I think that there are signs that the Chinese will need to reevaluate the way they use energy. Up until now, they have been assuming that they are going to require drastic increases on the supply side, and they really have not done a lot of detailed analysis of how they might reduce demand and use energy more efficiently, and there are projects underway being sponsored and ourselves to try to engage the Chinese and help them realize that energy efficiency should be an important part of the whole equation in China, as well as pricing, and I think the Chinese are beginning to realize that pricing also will be very important in their future. So, there are some signs that despite the current program plan, this may change in the future.

Mr. BILIRAKIS. Well, you know, according to the effective action that you refer to here that is required: the rest of the world, 30 percent; China, 7 percent; India, 4 percent; we are already up to over 40 percent there. You add in Brazil, which I guess is developing. It is not in that category, but in a sense, it is, and U.S.S.R., 14 percent. I do not know—these people are going to have to go back to their public, which is, for the first time, able to see the results of a little bit of progress, if you will, and a little bit of development, and tell them, "Hey, you have got to stop. We have got to stop."

What do we see there? You are in these meetings. Do we see the kind of mindset that is going to be willing to do this in the interest of the entire world, considering that it is in the interest of the entire world not for this generation or maybe not even for the next generation, but we are talking about it affecting us way downstream someplace, after we are 6 feet under?

Ms. **Fisher**. I do not think that we will be able to resolve the problem or deal effectively internationally if we go into it with the mindset that developing countries cannot develop and that is the solution. That is not going to fly, and that really has not been the attitude of the countries when they come together to meet. In fact, it has been how can we help and assist them in developing in the most environmentally efficient manner, and what can we, as a developed country, do to contribute to that learning, whether it is through new technologies or transfer of technologies.

Additionally, as I said earlier, we have not gotten to the hard questions yet, and maybe that is why everyone is cooperating, but one of the issues is going to be how is it that we as a developed country or world deal with the policy options that make sense to us, and how are we to accommodate growth in an environmentally acceptable manner in the Third World? Those are questions people are very aware of. They have not taken a north-south attitude, but it is a problem that is out there and people are very well aware of it.

Mr. **Bilirakis**. We have to be a leader, don't we? If we do not show them that we are willing to do some sacrificing and show some leadership not only in terms of words but in terms of actions, we are probably not going to get the cooperation that we might need.

Mr. Chairman, I know we are going to have to go. I was hoping we could hit recycling a little bit, too, because it is astounding to me that so many countries around the world have already had this and we are just not doing anything at all in that area.

Mr. **Sharp**. I plan to come back after we vote, but I wanted to let Mr. Synar have a chance to ask a couple of questions. We are down to about 8 minutes before we vote. In fact, I will turn the gavel over to the gentleman from Oklahoma, and I will get over and vote and come back, and we can just have a brief recess.

Mr. **Synar** [presiding]. Thank you, Mr. Chairman.

Just a few questions, if I could, Ms. Fisher. Your testimony today and also your comments during the questions have been that we want to be very aggressive, we want to show some leadership actions. In your testimony and the answers to your questions, you talk about planning, discussing, cooperating, meeting. Turn to the last page of your sheet, if you could, that you handed out to us. Are you prepared today to give this subcommittee some dates when these things will be completed? Take, for example, "obtain feedback on a report from the SAB and others".

Ms. **Fisher**. We have already gotten the feedback. We met with the SAB about 2 weeks ago, the beginning of April, and got their verbal comments, which is usually what we get first. They, then, submit to us a written report.

Mr. **Synar**. When will that be done?

Ms. **Fisher**. Probably 6 or 7 weeks.

Mr. **Synar**. All right. What about assess technologies, costs, and investments here? When can we expect that work to be completed?

Ms. Fisher. I do not think it will be completed. Those are going to be an iterative process. We hope to have more work—a supplemental report, perhaps, to what we have done already.

Mr. Synar. All right. What about analyze the domestic and international implementation options?

Ms. Fisher. Those are currently underway in the intergovernmental effort.

Mr. Synar. When will they be completed?

Ms. Fisher. We will have a report in the fall of 1990.

Mr. Synar. Fall of 1990?

Ms. Fisher. It will be an international report.

Mr. Synar. 1990? Okay. When will you complete the research on oceans, clouds, biological, and climate feedbacks?

Ms. Fisher. We are working with other agencies, which actually have far more expertise that we do in that area.

Mr. Synar. No completion date?

Ms. Fisher. Pardon me?

Mr. Synar. No completion date?

Ms. Fisher. Not a completion date, because again, that is going to be a lot of ongoing research, but there will be, again, an intergovernmental science assessment that will be done in the fall of 1990.

Mr. Synar. All right. The jackpot question: When is the completion date for the national policy, as required by the Climate Protection Act?

Ms. Fisher. We do not have a completion date either in the act or we have not set one in the administration, but I think that we will be, again, looking to the intergovernmental work and following on that.

Mr. Synar. Ms. Fisher, we have just gone down the list of the things that you say need to be done. You have not been able to give me a completion date, other than on one of them. That does not sound too aggressive to me.

Ms. Fisher. Well, actually, I disagree. I think we have been very aggressive. First, we were leaders in the Montreal protocol, which addresses CFC's, which is one of the major greenhouse gases. We have called for a strengthening of that protocol in terms of eliminating CFC's completely by the year 2000. Additionally, we have both financially and with our technical experts been a major contributor to the international analysis that has been done under the auspices of UNEP.

So, I think that both our work in terms of these two studies, which are a driving force behind the international effort, as well the contribution we have made there does, in fact, show a lot of leadership. We are not—we have not developed a specific policy recommendation yet. No other country has, but the work that we have underway, hopefully, will lead to very sound, well-though-out policy. Recommendations that our government can look at as well as the other governments.

Mr. Synar. Well, I appreciate that, and I take you at your sincerity, but as the gentleman from Florida said as he left, leadership means actions, not rhetoric and words, and sincerity will not work unless we complete some of these so that we can accept that leadership role.

Let me ask you just a couple of questions about China real quick. I met with Chinese energy officials yesterday. Are we presently involved in any joint ventures on energy with China?

Mr. MORGENSTERN. We have an agreement, actually, between our office and the Chinese EPA, which involves a number of exchanges on their part. Matter of fact, one of their senior people is visiting with us for the year, Dr. Lee——

Mr. SYNAR. I believe that I met with him.

Mr. MORGENSTERN [continuing]. And we are developing with them some work plans for them to actually produce——

Mr. SYNAR. Presently, we are not allowed, by law, to exchange capital and technologies, correct?

Mr. MORGENSTERN. I believe that is correct.

Mr. SYNAR. So, the discussions are about as far as we can go.

Mr. MORGENSTERN. Well, studies and discussions. That is right.

Mr. SYNAR. I will adjourn and go vote, and Mr. Sharp will be back shortly. We will recess for 5 minutes.

[Brief recess.]

Mr. SHARP [presiding]. The subcommittee will come to order.

Let me ask you, a number of the bills on Capitol Hill and communications to the administration have been from folks recommending a 20-percent reduction in CO_2 by the year 2000, I believe is the goal they set.

Can you help us understand what it would take to reach that kind of a goal of 20 percent by the year 2000?

Ms. FISHER. Dennis, can you put the bar chart up again?

Let me give you a feel for it.

First, that chart analyzed or laid out for you a variety of policy options that would be needed to get a 45-percent reduction from anticipated warming, 45 percent by the year 2050.

In order to get 20 percent by the year 2000 we would have to accelerate a lot of those activities and that is not a small matter.

We have not run the precise analysis you have asked for, which is what would it take and what would it cost to get a 20-percent reduction by the year 2000?

My own feeling is, kind of based on the analysis we did for this, is that it would be very, very difficult, undoubtedly very expensive, if in fact we could actually do it.

My feeling is the transportation efficiencies, the other efficiencies, the changes to alternative forms of energy supply away from coal or other fossil fuels will take time. The less time you allow yourself the more expensive it is going to be.

Capital investment takes many years to turn over capital stocks and if you try to accelerate that, you place on society—you do so at very high cost to society.

We are in the process of looking to see if we can refine some numbers to kind of crystallize in people's minds what it would take and what it would cost. We just haven't done that yet because as I said our report looked at the year 2050.

Mr. SHARP. But most of these things take a fair amount of lead time in order to——

Ms. FISHER. They take lead time in terms of developing the technologies and in terms of getting those technologies in place in society. When you are looking both domestically—when you look domestically, that is a problem. When you look internationally it becomes an even greater problem.

Mr. SHARP. Of course, one of the reasons to as quickly as possible determine the seriousness with which we are going to pursue this is so that at least as new powerplants are built that those newer facilities at least maximize efficiencies in terms of not only energy use but in terms of pollution. More powerplants are going to be built in the short period of time, am I correct, in China and the Soviet Union than in the United States, and you can choose different technologies yet today that make a difference.

Am I not right?

Ms. FISHER. I think that's——

Mr. SHARP. There's one kind of powerplant that will be much more polluting than another kind of powerplant.

Ms. FISHER. I think that is a very, very important point that we at the Agency have tried not to lose sight of and perhaps the Congress shouldn't either, and that is you don't have to decide to reduce emissions by 20 percent before the year 2000. What is perhaps more important is that as you look at the policies you are implementing today you pay attention to the greenhouse gas effects and incorporate that into your thinking, whether it says we draft the Clean Air Act and look to remedies to deal with ozone nonattainment or acid rain, that we do so in a manner that is as efficient as possible in terms of contributing to the greenhouse gas problem as we look toward developing technologies in terms of cars or houses or commercial industry, as we build some of the infrastructure of the Nation over the next few years or globally that we start to do things in a way that is consistent with our interest in reducing greenhouse gases.

I think that is probably more important and will get us a lot farther than trying to figure out whether or not we can hit a goal that is probably unreasonable to begin with.

Mr. SHARP. There is the one value I see in having, in establishing a goal nonetheless is precisely to force all of us to pay attention to how current policies are affecting the greenhouse. If you know you have to make some kind of improvement whether it is terribly realistic or not—I prefer to set realistic goals that we have some hope of accomplishing—but it at least forces you to reflect more intensely and dramatically in every private sector and every public sector decision.

If you don't have a goal out there and requirements out there, then your chances of doing that it seems to me it's so easy in Congress, it's so easy in the private sector to tradeoff for other values.

Ms. FISHER. I think that's true. I guess I fear a little bit that you end up wasting a lot of energy fighting over what the goal is and lose out on all the opportunities in terms of individual policy choices that could lead you if not to the goal, at least definitely in the right direction, but they do serve as a forcing mechanism.

Mr. SHARP. Well, I do think it is one of the reasons why, going back to the bully pulpit—it is not the only source of policy obviously but it is one of the reasons why Congress but especially the administration because they are more involved in international affairs obviously. Raising it on the agenda time and time again in many places is an important element of establishing that as you make current choices in whatever country and in this country too, we have a better chance of meeting some of these problems. I really realize it's unfair to put that on your shoulders as a representative of the administration but I think that is extremely serious that we have to accelerate what is historically a very, very slow process in terms of getting international cooperation and agreement, though the CFC agreement appears to have moved with speed that most would not have assumed in the past and even now the reexamination of that agreement as I understand it is going on to possibly and in my view should accelerate those goals. When that happens at least we are getting people's attention.

Let me go down your list just a little bit and get a little better sense of the proportions on this.

Can you give me any sense about on these policy things, let me just—it's hard. There are so many of them that I don't want to pull them all out but it is interesting that emission controls there are not viewed as nearly as significant, I mean they are important but not nearly as significant in terms of the percentage of reduction of future warming as simply the shifts in use of fuels, it appears to me, and energy efficiency.

Is that a fair statement?

Ms. FISHER. Emission control is aimed mainly at automobile emission controls and one of the reasons it is small is it presumes that the United States as we have has already put on a very strong tailpipe control.

The assumption in the analysis was that the rest of—is that all new vehicles in the United States would meet the current U.S. standards, so in other words we'd have complete turnover.

Internationally, what would it be? Or is that all vehicles internationally would meet the U.S. standard?

Mr. MORGENSTERN. I think it was all new vehicles in the United States would meet the U.S. standard and that in Europe they would adopt the U.S. standard and that stricter standards would be in place in the developing countries as well, although not necessarily at that level.

Ms. FISHER. So that focuses principally on the automobile.

Mr. SHARP. Oh, I see, yes.

Ms. FISHER. It doesn't get to other emission——

Mr. MORGENSTERN. There was also some controls implied for stationary sources, particularly low NO_x burners were implied to be in place.

Mr. TIRPAK. One other point of clarification. We did not assume emission controls for CO_2 for example. Almost all the technologies that we looked at were very costly and we did not expect that those technologies' costs would change very much in the future.

Mr. SHARP. Tell me about the energy emissions fee. Is that the CO_2 tax that we hear about? Is that what you are assuming there is the policy?

Ms. FISHER. We looked at the impact a CO_2 tax would have. Basically the kind of guts of the analysis was what would happen if your pricing of fossil fuel in fact reflected an environmental or social cost of using it. We did that for the purposes of this analysis by using a tax.

Mr. SHARP. Did you only look at a CO_2 tax, or was this a very gross analysis?

Did you look at different tax rates or did you get into the question of taxes on the different——

Mr. MORGENSTERN. It was a tax on different fuels. It was a tax on different fuels based on the carbon content.

For example, coal, which is approximately twice the carbon content of natural gas, the rate would have been correspondingly twice as much.

Mr. SHARP. And the response of the marketplace would either be to shift fuels or——

Mr. MORGENSTERN. Or conservation.

Mr. SHARP [continuing]. Or conservation or how about is there any assumption that technologically we can get a better combustion that will in fact mean less CO_2 or is that scientifically——

Mr. MORGENSTERN. Well, the one technology that we are aware of is the one that Dr. Tirpak just mentioned which is the kind of end of the pipe CO_2 scrubber. We see that as being prohibitively expensive.

Mr. SHARP. The commercialized biomass, is the presumption there that we would do strong interventions in the marketplace to bring that into more common use or is it the assumption that that's a developing——

Mr. MORGENSTERN. There are kind of two pieces there.

First was, we assumed that there would be the active planting of high yielding trees which would in fact grow rapidly and would produce biomass relatively cost effectively.

Second, there would be the introduction of combustion technology as is now used in some very advanced turbines where this biomass would, principally could be combusted efficiently.

We believe as do many other experts that in fact this type of technology would become cost effective some time in the next century relatively early and we see that principally I should say in developing countries as opposed to—perhaps some in this country but it would largely be a developing country option.

Mr. SHARP. You are assuming the production of steam?

Mr. MORGENSTERN. That's right. You simply burn the combustible wood.

Mr. SHARP. Let me ask my colleague from Florida if he has any questions.

Mr. BILIRAKIS. Well, regarding this same chart that I have been looking at also, is this worldwide? Is this contemplated for worldwide, the relative effectiveness or is this the United States?

Mr. MORGENSTERN. All of this was done on a global basis. The whole theme of this report is that the United States should not act alone, cannot act alone when we're only 20 percent of the problem anyway.

Mr. BILIRAKIS. So we are talking about imposing or getting other countries to impose an energy emissions fee?

Mr. MORGENSTERN. The way we did this, this was the result of a modelling effort that used a global model and in fact there were nine different regions of the world which we looked at and there were different assumptions which were built into each region.

We are not assuming that there would be exactly the same standards applied all across the world, but yes there would be some action in all parts of the world, however, in each of these areas.

Mr. BILIRAKIS. In the nuclear power here you have this 5 percent figure. That's based on today's world, which means no additional reactors in the United States?

Mr. MORGENSTERN. Well, actually the way we did that is we assumed that the share that nuclear power would hold of the world market is approximately the share that it has now of the world electricity market, which is about 15 or 17 percent.

In order to attain that, given the growth and demand that would occur, you might see the construction of several hundred nuclear plants by the next century would be consistent with that.

Mr. BILIRAKIS. What's the largest figure through the year 2050 here, the largest bar is commercialized biomass.

Very briefly, what does that mean?

Mr. MORGENSTERN. I just responded——

Mr. BILIRAKIS. Oh, did you?

Mr. MORGENSTERN [continuing]. Really to the chairman's question on that point. I think one of the things you have to keep in mind in this whole chart really is that all of these reductions are relative to a base case.

That is to say we are assuming some set of activities in the future and for example natural gas appears to be very low in this chart. If you are looking at it you say gee, this is a rather small number compared to biomass. Well, the reason is that we're assuming a great deal of natural gas is in the base case. We are assuming a great deal of natural gas is used and certainly natural gas, the use of natural gas would be consistent with reducing greenhouse gas emissions.

With biomass there is not very much in the base case. That would be something that would be——

Mr. BILIRAKIS. So there is room for——

Mr. MORGENSTERN. There's room for growth. It would be era of policy innovation, that's right.

Mr. BILIRAKIS. I did say, before we ran to vote, I had some questions on recycling. I would like to get back to that. Is that just a very small part in this overall picture, and I suppose you could be considering that in the agricultural landfill cement portion? You know, we tend to travel at times, some more than others, we Members of Congress, around the world, but I do not find—I have the impression that other countries around the world are way ahead of us when it comes to recycling. You can almost see that by virtue of the debris or lack of debris, if you will, on their highways and on their sidewalks and whatnot. Is that a true statement? Are we way behind, No. 1, and No. 2, is that a significant enough area that maybe we can concentrate on, particularly in view of our previous discussion regarding our showing some sort an effort here, some sort of a leadership effort, and whatnot?

Ms. FISHER. Let me answer No. 2 first. Landfills are a part of the problem, because they contribute methane, and therefore, recycling can be part of the solution. In terms of its overall percentage, it is small, but my feeling is anything that helps should be looked at and, perhaps, aggressively pursued, especially those things that are good for other environmental reasons, and recycling is good not only because it may make—even though it is a modest contribution to helping in terms of warming, it makes sense for a lot of other very important environmental concerns. So, I am and the Agency—the Administrator is an advocate of recycling and is putting in place a program at EPA to aggressively pursue that.

Mr. Bilirakis. Are we doing anything here in the Congress to sort of help his efforts in trying to put into place whatever it is he is trying to put in place regarding recycling?

Ms. Fisher. You have pollution prevention legislation, which I am not sure whether it includes provisions concerning recycling. So, in terms of kind of the general interest in recycling, I think it is up here as well as in the administration, but it is also hard, because it is something that—you want people to change behavior. So, it will take an aggressive effort by both the administration and Congress.

Mr. Bilirakis. Changing behavior in an area like that seems to me to be a heck of a lot less painful than—well, we can talk about coal and an emissions tax and whatnot, and I am not sure what that is supposed to accomplish. Granted, it brings in some revenue. Second of all, it might result in some efficiencies because of the tax in terms of usage, but probably put a few more coal miners out of work, and I do not have any coal mines in Florida, but I guess what I am saying is that so many of these other areas which we definitely should continue to pursue, and I commend you for mentioning them, also result in some sacrifice as far as the American is concerned, which is all right, too. But when it comes to recycling, for crying out loud, it does not hurt anybody. In fact, it probably will help us to improve in terms of self-discipline and some of our behavior patterns.

Ms. Fisher. I agree.

Mr. Bilirakis. Thank you very much. Good report. I learned a lot this morning.

Ms. Fisher. Thank you.

Mr. Bilirakis. Thank you, Mr. Chairman.

Mr. Richardson [presiding]. I thank the gentleman.

Ms. Fisher, I obviously am getting prepared to ask you some questions that are in the script, but I am going to ask you something that is not in the script, and that is the internal U.S. Government policymaking function, as it comes to international environmental affairs, do we have an efficient, effective bureaucratic response to global warming? Do we have a national security council to expedite, as the National Security Council [NSC] does in foreign policy, to bring—synthesize the bureaucracy together? It is a very openended question. Maybe you are the czar and maybe these gentlemen are your junior czars, but are we responding adequately? Is it strictly the State Department that takes the lead, or do you take the lead? Give me an honest response, and how can we make it better?

Ms. Fisher. Okay. Two points: First, we are very coordinated with the State Department. We work with them all the time. They attend many of our meetings, and we attend many of their meetings. When I say we are coordinated, it involves not only the State Department and EPA but many of the other Federal agencies that are affected by or concerned about global warming, including the Department of Agriculture, who would suffer a real impact if, in fact, we had significant warming; the Department of Energy, whose policies go the very heart of some of warming concerns; the Department of Interior; the science organizations such as National Science Foundation [NSF], National Oceanic and Atmospheric Administration [NOAA], and National Aeronautics and Space Administration [NASA]. All contribute and we are coordinating.

Could we do it better? Probably. The President has said that he intends to issue an Executive order that will lay out more clearly how the government is going to organize and respond to global warming. Meetings on that are in the process of beginning, but we are coordinating and working well together, but we have not officially, as you suggested, named a czar yet.

Mr. RICHARDSON. What about this meeting you are having in Geneva, the Intergovernmental Climate Meeting? What is going to be the agenda?

Ms. FISHER. Two things: The first 2 days—let me back up 1 second, because you missed a discussion earlier. The intergovernmental panel has been subdivided into three special work groups. One work group is the Response Strategies Work Group. That is the group that is going to be meeting in Geneva. The first 2 days will be technical meetings that will look at issues such as energy technology and conservation. The last 2 days are going to be a meeting of the heads of all the delegations on that panel, which is approximately 17 countries, to talk about the work that has progressed since the last meeting, which was in January, and the work that remains to be done between now and when the reports are to be submitted, which is the fall of 1990. So, it will be both a technical meeting as well as a meeting of the leaders of the group.

Mr. RICHARDSON. But it will not be high level—it is mostly technical people.

Ms. FISHER. The first 2 days will be very technical. The second 2 days will have, from our government, two—I will be going as an Assistant Administrator and an Assistant Secretary of State will be going. Quite honestly, we will probably outrank some of the other countries there.

Mr. RICHARDSON. Who is the Assistant Secretary for Oceans and Environmental Affairs now?

Ms. FISHER. Dr. Fred Bernthal.

Mr. RICHARDSON. That is the position Negroponte had before?

Ms. FISHER. Yes, that is exactly correct.

Mr. RICHARDSON. Is this individual a political appointee or a career person?

Ms. FISHER. He is a political appointee.

Mr. RICHARDSON. And he has been confirmed?

Ms. FISHER. Yes. He was confirmed, actually, about a year—maybe 1½ years ago, and it is my understanding he will be staying and serving for Secretary Baker.

Mr. RICHARDSON. Many people are talking about an effective doubling of CO_2 occurring by the middle of the next century, and as I understand it, effective doubling means that you also count other greenhouse gases, such as CFC's, and translate them into CO_2. Now, if we also take methane, CFC's, nitrous oxide, ozone, how close are we to an effective doubling of CO_2? I assume that is a technical question.

Ms. FISHER. I am going to pass that on.

Mr. RICHARDSON. You are going to defer.

Mr. MORGENSTERN. How close are we? Well, we have a series of projections that are in our report, and I think we are looking at an effective doubling by the first half, certainly, of the next century. I am looking on the page of my report where I can give you a more precise answer.

Mr. TIRPAK. The answer is someplace between 2030 and 2040.

Mr. RICHARDSON. Now, have we seen the magnitude of warming that the scientists would predict, given that increase in concentrations?

Mr. TIRPAK. We have not seen the magnitude of warming as of this date, no. We can only estimate a range of warming that would actually occur at that time in the future.

Mr. RICHARDSON. Okay. So, did you say between 20 and 45?

Mr. TIRPAK. Between the years 2030 and 2040, someplace in that range.

Mr. RICHARDSON. Okay.

Mr. MORGENSTERN. The answer, I think, is that, you know, right now, CO_2 concentrations have gone up about 25 percent since the beginning—say, over the last 150 years, and we are saying that CO_2 concentrations would double over that timeframe to the middle of the next century, 2030, 2040, 2050.

Your question is really what are the temperature implications of that increase in concentration, and there is two parts to the answer, okay? One part is there has been some observed increase in temperature over the past 100 years. In fact, there is some dispute among scientists as to how much that really is and how you measure it. There are questions of how many weather stations there are, whether the actual readings are affected by urbanization and other issues. The question about the future—and in fact all the work that is in our report, and I believe the work that is really around in other studies as well, is based upon models.

Mr. RICHARDSON. Now, are we seeing enough of what we expected in the 25 percent?

Mr. MORGENSTERN. Well, as I say, the question is how much warming has actually occurred in the past, if you want to divide into the past and future, okay? In the past, the best estimate and the one that we have used is on the order of three-tenths to seven-tenths of a degree centigrade of warming has actually occurred, but in fact, there is a rather—very rich literature on how you measure it and how much has actually occurred, and there is some dispute about it.

Mr. RICHARDSON. Now, you prepared, Madam Secretary, a report, "Policy Options for Stabilizing the Global Climate". Did you actually come up with a set of policies that actually would stabilize the climate?

Ms. FISHER. We did not come up with a set of policy options that would stabilize greenhouse gases. We came up with a set of policy options that would reduce significantly emissions of greenhouse gases, but quite honestly, in order to stabilize the concentrations of greenhouse gases in the atmosphere, the policy options would be extremely Draconian, and we did not feel that they would be of particular help to policymakers in trying to make some tough decisions. In fact, we thought we could get a lot of improvements by the ones that we discussed, by they do not, in fact, take you down to a stabilized atmosphere.

Mr. RICHARDSON. But it is a feasible goal to have a stabilized atmosphere, correct?

Mr. MORGENSTERN. No. I think what we are saying is that on the basis of our analysis, we believe that the reductions in emissions that would be required in order to obtain a stabilized atmosphere would be more than, in our view, it is practical to realistically consider, and so, we did not think that proposing them or even discussing them in any detail in our report would be helpful to the Congress.

Mr. RICHARDSON. But what is a feasible goal? I mean we have plenty of people in the bureaucracy that are giving us options. Whenever the do not want to make a decision, they say, "Well, here are the options", and we turn to our scientists and we want a little bit more than that. Why is it not a feasible U.S. policy goal to have policies laid out that lead toward the stability of the climate? I do not understand.

Ms. FISHER. Two points: First, some of the things you might look at are the use of almost no coal as a source of energy in our country or around the world. That is a very difficult thing for our country to do, let alone many other economies. I mean that is just an example of some of the stringent-type things you might have to look at. Second, we thought you could go a long way toward realizing your goal in terms of limiting ultimate temperature increase by a lot of the policy options that we did put on the table. In other words, you could address a large part of the problem by focusing on a lot more reasonable sense of policy options, and we thought that would be a lot more fruitful place to have the discussion.

Mr. RICHARDSON. Sounds like you have been talking to the State Department.

Ms. FISHER. Maybe I hang around with them too much.

Mr. TIRPAK. Let me also add that I think our—some of the thinking behind what we did is that we would expect that over the next 5 or 10 years there will be a considerable amount of research done to try to clarify the kinds of goals that might be appropriate. For example, we are not certain, right now, how rapidly forests can begin to shift and move and adapt to climate change. We have some preliminary sense of that, but if we knew more about the impacts on the ecological system and what it could tolerate by way of temperature changes over time, how rapidly temperature changes would affect those systems, then we could begin to think about what would be a target goal that would be acceptable for the environment, and some people are beginning to think about that, and there is work underway, but it is a little too early to try to translate that kind of a goal into, say, an emission target or something like that at this time.

Mr. RICHARDSON. Let me conclude by asking you a question on fuel efficiency. Your assumptions for future improvements in automobile fuel efficiency. What efficiency goals do you think can be met by this time, Madam Secretary?

Ms. FISHER. What we laid out is that automobile fuel efficiency would reach I believe 40 miles per gallon [mil/gal] by the year 2000 and we have 50 miles a gallon later than that?

Mr. MORGENSTERN. Yes. We have 40 mil/gal for new cars by the year 2000 and a fleet average which would imply the turnover of cars of about 50 mil/gal by the year 2025.

Now let me just mention that there's been some discussion, there have been several hearings held on the Senate side in the past few weeks on this issue about how practical this is and in fact, it's a raging debate, I'll just call to your attention that the Department of Energy has testified on the record that they think improvements somewhere between the mid-1930's and in one case up to 40 miles per gallon for passenger cars would be both technically and in some sense economically achievable by the year 2000.

So this is an assumption. It's certainly in line with some other work that's been done.

Mr. RICHARDSON. What is the technical back up support for this and what kind of comments have you received on this proposal of yours?

Mr. MORGENSTERN. Okay. I think there are two parts to that answer. In terms of our own work, we have not done independent analysis of the technology associated with improving fuel efficiency of cars.

We have reviewed the literature that's out there. There's a range of studies, some by DOE, some done internationally, some by private consultants and we have a very thorough review which is all cited in our study.

The Department of Energy as I say has recently testified in a way that would support this type of—these types of assumptions but at the time that we did this work, we presented them simply as assumptions. We said that we think they are credible assumptions. We were not predicting or taking a position that they should be the case. We were using them as assumptions but we do think they are credible.

Mr. RICHARDSON. What are the tradeoffs between achieving greater efficiency and reducing local air pollution problems?

Mr. MORGENSTERN. Well, in fact, there are many actions that could be taken that would in fact improve local air pollution problems and also help the global warming problem.

For example, the use of some of the measures under discussion in California which would have the effect of reducing driving if they were to take place would both reduce emissions and reduce greenhouse gas emissions—CO_2 emissions.

Mr. RICHARDSON. Now are you looking at ways to not penalize domestic auto concerns in the CAFE standards?

Mr. MORGENSTERN. In fact we are. This is a very interesting discussion. It's been the topic of some concern. There are questions about whether you would for example—how you would deal with credits. There's a fair number of credits that have been developed both by American producers and of course, many more credits have been developed by foreign producers.

Mr. RICHARDSON. What do you mean credits?

Mr. MORGENSTERN. Well, the way the system works as I understand it, there's the 3-year banking of—carryforward and carry-back, I guess and there are considerable credits developed, in fact many more by the foreign producers. There may be some way to look at that which could have favorable indications.

There's also been discussion of looking at different standards for different size classes although I think that may have some problems but all these are kind of ideas and we still don't have a position on the subject and we are doing some studies as to the potential way to——

Mr. RICHARDSON. Would it be possible to impose some international CAFE standards?

Mr. MORGENSTERN. That would be kind of tough. Each country tends to be sovereign in this area.

Mr. RICHARDSON. You've got to start somewhere. Why not—why wouldn't that be a—I know it would be a noble goal but why not try to do something?

Ms. FISHER. Congressman, one of the things that the intergovernmental panel is looking at is how best to approach policy emission reductions, whether it's through CAFE or other, internationally and one of the things they're going to look at is if they take the approach that we did in CFC's which is an across-the-board phaseout. Actually the current protocol calls for a 50-percent reduction but it was one action imposed internationally.

We need to look on climate, whether that approach makes sense or whether countries should take different actions that still result in emission reductions but perhaps in one country, some might be easier or more cost effective than in other countries.

In other words, we would be looking at rather than doing one thing globally, maybe doing a variety of things globally, with each country looking to policies that more efficiently or effectively would work given their society or economic or political systems.

So they will be looking at whether we should do as I said one thing broadly or a variety of things.

Mr. RICHARDSON. I know this probably was asked at the hearing earlier by my colleagues but when are you going to submit your clean air legislation to the Congress?

Ms. FISHER. Every question to an administration witness comes down to the Clean Air Act. We are still trying to meet the goal of the end of May, beginning of June. It is on a track to do that. Our Agency has been very, very involved in trying to develop the document working with the rest of the government and the Administrator and the President have both committed to the end of this month or the first of June, somewhere around Memorial Day.

Mr. RICHARDSON. How much of an international component will you have in that legislation? I know the Director has come out for a CFC ban by the year 2000. Will that be in the legislation?

Ms. FISHER. No, that will not be in the legislation. We are moving to do that through the Montreal protocol process. We will be renegotiating that process sometime in the course of the next year. So the Clean Air Act will not address that.

A couple of points. I think the Clean Air Act—the options that the administration is looking at try to take into account the effects on global warming, in other words, energy efficiency and that sort of thing. Other than that, the only international issue I think at this point in the Clean Air Act would be the acid rain proposal which is of interest specifically to Canada.

Mr. RICHARDSON. Why couldn't we have the CFC proposal as part of your legislative goals to Congress for this country?

Ms. FISHER. Well, we don't really need legislation to move forward on CFC's right now. We are currently—I think it's under one section of the Clean Air Act—I can't remember which one—157—that was the section that led us to the current process that we are involved in which is the Montreal process and we believe that legislatively and then internationally through the treaty, the process is in place for us to accomplish what we need to and that is the total phaseout of CFC's. So we don't see a legislative fix as needed on that.

In terms of proposing a bigger global warming initiative, two points. First, we aren't quite there yet in terms of the analysis and in terms of the position—first of all. Second, as you know, the Clean Air Act is complex enough and trying to get it through with acid rain and ozone nonattainment may prove to be enough without having to add a global climate section to it.

Mr. RICHARDSON. There are some of us that may proceed on a separate track and obviously we'll consult with you. Let me just say that I did not attend the earlier part of the hearing but I think this is a very important hearing and we're discussing some very important issues—not as sexy as others but probably as equally as important.

I thank you for the testimony and let me just say that the Administrator of the EPA has my support and I want to make that comment off the record because I know it would severely damage him within the Republican administration.

Ms. FISHER. I will tell him of your——

Mr. RICHARDSON. Keep that as off the record, not that it matters but the hearing is adjourned. I thank the witnesses.

[Whereupon, at 12:13 p.m., the hearing was adjourned.]

[The following material was submitted for the record:]

U. S. DEPARTMENT OF COMMERCE
INTERNATIONAL TRADE ADMINISTRATION
WASHINGTON, DC 20230

JOINT COMMENTS ON THE U. S. ENVIRONMENTAL PROTECTION AGENCY'S

POLICY OPTIONS FOR STABILIZING GLOBAL CLIMATE DRAFT REPORT TO CONGRESS FEBRUARY 1989

OF:

American Iron and Steel Institute
American Mining Congress
American Nuclear Energy Council
American Paper Institute
American Petroleum Institute
Association of Home Appliance Manufacturers
Business Roundtable
Chemical Manufacturers Association
Edison Electric Institute
Electricity Consumers Resource Council
Motor Vehicle Manufacturers Association
National Association of Manufacturers
National Coal Association
U.S. Chamber of Commerce

April 21, 1989

JOINT COMMENTS ON THE U. S. ENVIRONMENTAL PROTECTION AGENCY'S POLICY OPTIONS FOR STABILIZING GLOBAL CLIMATE, DRAFT REPORT TO CONGRESS. FEBRUARY 1989

I. INTRODUCTION

In February 1989. the Office of Policy Analysis at the U.S. Environmental Protection Agency (EPA) released its three-volume draft report to Congress: Policy Options for Stabilizing Global Climate (herein referred to as the "Draft Report" or the "EPA study"). This report is the product of one of two studies on the greenhouse effect that Congress directed EPA to undertake.[1]

The Draft Report has been distributed to several federal agencies and was the subject of extensive review by the EPA's Global Climate Change Subcommittee of the Science Advisory Board (SAB) on April 4 and 5. 1989.

In a memorandum dated March 22, 1989. the International Trade Administration at the U.S. Department of Commerce solicited the views of the business community as part of that agency's review and evaluation of the Draft Report. We welcome the opportunity to comment on this extremely important and timely effort.

II. Summary

A. A Summary of the Business Community's Position on Enhanced Global Climate Change

- The business community is concerned about the potential for enhanced global climate change brought about by man's activities. and will actively participate in the continued study of this phenomenon and the development and implementation of appropriate policy responses.
- Science must serve as the foundation for policy. Evidence does not now exist to support immediate actions by the U.S. or the international community in an attempt to drastically curtail or change energy use.
- Policies that are intended to reduce significantly the rate of climate change in the short-run. may in fact. carry huge economic and social costs that are counterproductive in the long-run.

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[1] The second study was to focus on the potential health and environmental effects of climate change. The EPA report. The Potential Effects of Climate Change on the United States. addressed that request and is undergoing final review by the Agency. FY 1987 Continuing Resolution Authority.

- Climate change is a "global" issue that must be addressed through cooperative multilateral programs. It would not be prudent for the U.S. to initiate broad unilateral actions that will have little or no effective environmental benefit if other nations do not participate.

B. A Summary of Comments on the EPA's "Draft Report"

- The EPA study's format and inherent limitations must be recognized. Its lack of any meaningful economic analysis is a serious if not fatal flaw if the report is used for policy-making purposes. The study's policy options or stabilizing strategies will inevitably be misinterpreted as recommendations. and the study's "No Response" and "Stabilizing Policy" scenarios will be misconstrued as forecasts.

- It is impossible to predict the relative potential of each technology or policy option for reducing greenhouse gases individually or as a group, absent a detailed cost analysis.

- The scenarios which were developed by EPA to provide a conceptual framework for policy analysis lack any consistent economic basis. The assumptions in each scenario are therefore more impressionistic and anecdotal.

- The Draft Report over-emphasizes policies that limit the production of energy and does not adequately address countervailing consumption behaviors.

- The EPA study likely exaggerates the near-term potential of biomass and solar energy as major contributors to mankind's primary energy needs. Climate stabilizing policy options must be technology neutral.

- Expanded use of technologies that more efficiently utilize fossil-fuels may be more cost-effective and politically feasible than efforts to significantly decrease the use of fossil fuel combustion.

- Nuclear. hydroelectric and geothermal power are all proven technologies that do not emit greenhouse gases. The role of these technologies needs to be expanded in the EPA's assessment of technology options. If policy options are being evaluated to mitigate global climate change. it would seem prudent if not absolutely essential to consider all technology options. In selecting the most effective options, environmental. social. and economic tradeoffs must be recognized.

- An overcommitment to near-term technology options may limit or stop development of more effective and politically or socially acceptable long-term options. EPA must not encourage policies that inhibit the process by which new or emerging technologies reach fruition.

- Policy options must not be advocated that are mutually inconsistent. For example: existing commercially available substitutes for CFC-11 and CFC-12 do not have comparable energy efficiency capabilities which do not also potentially contribute to the greenhouse effect. Therefore, some efforts to mandate higher energy-efficiency standards for refrigerators and freezers are presently impossible, as well as contradictory.

- Different climate stabilizing strategies may have to be designed for developed and developing nations. These strategies may vary significantly with respect to their timing and costs.

III. THE POSITION OF THE U.S. BUSINESS COMMUNITY ON ENHANCED GLOBAL CLIMATE CHANGE

The business community is concerned about the possibility of "enhanced" global climate change brought about by man's activities. We will actively participate with governments, academia, and other groups on the continued study of this phenomenon and for the development and implementation of appropriate policy responses.

Therefore, we believe that science must serve as the foundation for policy. EPA's draft report highlights the poor state of existing knowledge concerning the mechanisms of the global climate, as well as the uncertain effect of various policy options. These uncertainties must be lessened greatly before governments can make informed policy choices. Clearly, there is considerable uncertainty in the science related to our predictive capabilities and the accuracy of our measurements of the interactions among the oceans, atmosphere and biosphere. These measurements bear directly upon the basic assumptions regarding the possible rate of change, and the regional impacts. We recognize that certain atmospheric gases, which are collectively known as "greenhouse gases," have the potential for increased "global warming".[2] Our climate as we know it would not otherwise be as it is. Scientific measurements confirm that concentrations of these gases in the Earth's atmosphere are increasing and some at relatively rapid rates. The statistical mean global temperature also appears to be rising, although very slightly. However, long term statistical mean global temperature analysis is uncertain.

Societies' responses to the prospect of enhanced global climate change should be guided by actions that strive to maintain future flexibility that can reduce long-term risks and costs. Any immediate actions should have compelling corollary benefits. We do not believe that sufficient evidence exists to require immediate actions by the U.S. or the international community in an attempt to drastically curtail or change energy production and consumption and agricultural/land-use patterns. In fact, there is potential risk from such a crisis management approach.

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[2] The major greenhouse gases are: water vapor (H_2O), carbon dioxide (CO_2), nitrous oxide (N_2O), methane (CH_4), carbon monoxide (CO), chlorofluorocarbons (CFC-12 and CFC-11), other oxides of nitrogen (NO_x) and tropospheric ozone (O_3).

More and better integrated research is definitely the first step. We will continue to offer our assistance in reviewing the U.S. research agenda and in providing guidance on the establishment of research priorities.

Paralleling our support for better integrated research, industry has and will continue to identify and develop industrial processes and energy technologies, policies, and products that reduce greenhouse gas emissions. This includes the application of new technologies. Specific examples include: decontrol of natural gas pricing, forest management improvements, pollution prevention (including recycling), tropospheric ozone controls, methane recovery from landfills (where practical), utilization of innovative clean coal technologies, revitalization of nuclear power, and energy efficiency investments. However, these efforts should:

- be cost effective,
- enhance energy productivity,
- contribute to economic growth, and
- not adversely impact our competitiveness in international markets.

We support these efforts now, as the research agenda goes forward, with the assumption that economic health is essential for continued worldwide development of climate change response strategies. Policies that may appear to significantly reduce the rate of climate change in the short-run, may in fact, carry huge economic and social costs that are counterproductive in the long-run. Drastic government intervention in the marketplace to "solve" immediate concerns on enhanced global climate change carries the potential for major social and economic impacts, inequitably distributed among peoples of the earth.

Any actions on global climate change must be an international effort. No single nation can significantly lessen the potential for climatic change on its own. Even an economy as large as the United States could be seriously harmed by policies to restrict the generation of greenhouse gases, especially if these policies are not followed by other nations. Such actions would create the worst of all possible situations by wounding this country without significantly reducing global warming. As such, we support the program and goals of the Intergovernmental Panel on Climate Change (IPCC) and support an active leadership role by the U.S. participation in the IPCC. We are already working with the U.S. delegation, providing our advice into the IPCC process.

While we agree with those who call upon the U.S. to "take the lead" in acting on this issue, we must avoid hastily implemented policies that can cause severe economic impacts to U.S. businesses and U.S. competitiveness worldwide. Rather the U.S. should continue its demonstrated leadership through actions already adopted on CFCs, funding for research on science and alternative technologies, and its resource commitments to the IPCC.

Consistent with our views as stated above, we support the efforts of President Bush, the EPA, and the Departments of State, Energy and Commerce and others in defining the role of the U.S. in the IPCC.

IV. SPECIFIC COMMENTS ON EPA'S DRAFT REPORT

The EPA took a holistic approach by addressing all major greenhouse gases in this report. However, the report is forced to use assumptions, use incomplete and inconsistent models, and list various technologies without thought as to how they may relate to each other. Moreover, the report does not, and could not, assess the economic effects of policy options or the influence of economic or social forces on policy outcomes. Despite the report being more complete than any other to date, its most important message is just how little we know at this time.

A. The Limitations of the Draft Report Economic Analysis

The authors of the Draft Report were generally forthright in their assessment of the study's major limitations. Specifically:

> Economic linkages are not fully captured. The type of economic analysis conducted cannot ensure that the activity levels assumed in each sector are completely consistent with the aggregate economic assumptions. In addition, capital markets are not explicitly considered.[3]
>
> Detailed cost analyses have not been conducted. Technological strategies have been screened based on judgments about their potential to be cost effective, but no attempt has been made to rank the cost-effectiveness of each strategy or to estimate the government expenditures on total social costs or benefits associated with the stabilizing strategies.[4]

The above caveats notwithstanding, the lack of any meaningful cost analysis in the study is a serious if not fatal flaw if the study recommendations are used for policy-making purposes. The "policy options" or "stabilizing strategies" in the report will inevitably be misinterpreted as recommendations, and the "No Response" and "Stabilizing Policy" scenarios will be misconstrued as forecasts.

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[3] Draft Report, Executive Summary, p. 9

[4] Ibid., p. 10

Two forms of economic analysis are essential for evaluating potential technology or policy options for climate stabilization.

1. A Comparative Economic Study
2. A Macroeconomic Impacts Study

A comparative economic study is necessary to rank options in terms of their overall costs and success of implementation. This includes a thorough cost-benefit analysis which incorporates both upstream and downstream effects of proposed actions. The commercial status of new, emerging or untested technologies must be recognized and their costs adjusted accordingly. Non-cost considerations such as lifestyle changes and institutional, social, or cultural barriers must be assessed in market penetration studies which determine the likely degree of success of each option. Absent this detailed cost analysis, it is impossible to predict the relative potential of each technology or policy option for reducing greenhouse gases in the atmosphere.

The second form of economic analysis is the estimation of macroeconomic impacts. Mandated policy options of this scale will face capital constraints, stimulate inflation, dislocate jobs, and force taxes or national debt levels to rise. The market-oriented economics of the OECD, the centrally-planned Eastern Bloc economies, and the developing and "mixed" economies in the Third World will all be shocked by any concerted international effort to regulate the chemical composition of the Earth's atmosphere. The EPA study totally ignores these shocks.

Macroeconomic feedbacks in global economic systems may contribute considerable uncertainty to the effectiveness of different stabilization strategies. Therefore, they must be evaluated if the tremendous risks and costs of mandatory policies are to be minimized. If further scientific evidence verifies the onset of enhanced global climate change, and that is a big "if", detailed macroeconomic studies may be necessary to assess the trade-offs between policies that attempt to stabilize climate change and those that help societies adapt to climate change.

B. Scenario Development for Policy Analysis

The EPA study includes four scenarios of future patterns of economic development and technological change. These scenarios are disclaimed as forecasts, per se, but nonetheless are characterized as "pictures of how the world may evolve" and are used as " a basis for evaluating strategies for stabilizing the atmosphere."[5]

Two of the scenarios assume that no policies are implemented to restrain greenhouse gas emissions. One assumes relatively modest ("slowly changing") economic growth: the other assumes somewhat more robust ("rapidly changing") growth. These scenarios are referred to as the "No Response" scenarios.

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[5] Ibid., p. 20.

The other two scenarios assume that climate stabilizing strategies are implemented. These strategies include major reductions in fossil fuel usage. CFC phaseout, decreased deforestation, increased reforestation, energy efficiency improvements, and the increased use of solar and biomass energy resources. Like the first two scenarios, there are also ''slowly changing'' and ''rapidly changing'' scenarios. Ostensibly, these ''Stabilizing Policy'' scenarios are used to rationalize and advocate action that is limited to the handpicked strategies included in these scenarios. Hence, policy ''options'' are implicitly cast as policy ''recommendations.''

The use of scenarios for developing a conceptual framework for policy analysis is a legitimate and perhaps, necessary exercise. However, absent any economic bases for the structure of each scenario and the dynamics between alternative scenarios, the assumptions become self-serving anecdotes.

A significant problem with the manner in which these scenarios were developed is the fact that major economic assumptions were held constant across each pair of ''No Response'' and ''Stabilizing Policy'' scenarios and are therefore internally inconsistent. In other words, GNP growth, population growth, the availability of capital, technological innovation, and energy price behavior are assumed to be insensitive to the implementation of climate stabilizing policies.

This would of course be untrue and to retain these scenarios in the report would be very misleading.

In its final draft on this study, the EPA should discuss scenario development and its application to policy formulation. No scenarios should be arbitrarily created until detailed economic studies have been performed on all viable mitigation options and strategies. EPA should regard this effort as only the beginning of the process of identifying, evaluating and choosing policy options, rather than the conclusion of this process.

C. The Treatment of Production and Consumption Oriented Policy Options

The Draft Report over-emphasizes policies that limit the production of energy (and greenhouse gas emissions) and does not adequately address consumption behaviors. Demand-side ''feedbacks'' of limits placed on the production of fossil-based energy and CFCs, for example, are totally ignored. This concern is related to the need for market penetration studies as mentioned above in section IV-A.

Consumption behavior, i.e., human activities such as cooking, bathing, heating and air conditioning, transportation, and housing investments, will not be static under any climate stabilizing strategy. Missing from the EPA's study is the adequate recognition of countless and complex price and income elasticity effects. For example, the manufacture of more energy efficient refrigerators may not eliminate the demand for larger units that offset the efficiency gains. Total energy use may not decrease after the purchase of a more efficient appliance. Similarly, promoting high-efficiency air conditioners does not stop the consumer from lowering his thermostat setting or running the unit more frequently.

D. Energy Efficiency Improvements Versus Fossil Fuel Phaseout Policies

An important element in EPA's policy proposals is a sharply increased reliance on renewable energy resources, particularly biomass and solar (photovoltaics). The role of biomass as a primary energy source is envisioned to expand from approximately none (excluding existing non-commercial uses) to 21 to 30% of total demand by the year 2050 and to at least 35% by the year 2100.[6] Photovoltaic solar power is proposed to expand to 9 to 15% by 2050 and to 20% in 2100.[7]

Heavy utilization of these sources represents a radical departure from present global patterns of energy supply and demand. This scenario is highly speculative and downplays potentially more cost-effective technological options -- especially in the near-term where EPA suggests a great sense of urgency.

Clean coal technologies, cogeneration, fuel cells, magnetohydrodynamics (MHD), and advanced gas-fired combustion technologies are mentioned, but are effectively dismissed as viable options.[8] We believe that some of these options may be more cost-effective and politically feasible in the near-term than any effort to mandate the phaseout of fossil fuel combustion altogether. If the goal is to reduce greenhouse gas emissions, climate stabilizing policies must be technology neutral, if these policies are to minimize overall costs and risks.

Some options are emerging technologies and are not yet available for widespread commercialization. These options are not given a prominent role in the EPA's stabilizing policy scenarios because of existing uncertainties and other obstacles. Given the over 100 year planning horizon assumed in the scenarios, EPA's assessment of the longer-term viability of these options is unduly pessimistic. Ironically there is no such bias in their rather bullish assessment of biomass. The Draft Report concludes that "[m]ore advanced technologies for producing, collecting, and converting biomass to gaseous and liquid fuel and electricity could become economically competitive within the decade."[9] We do not dismiss the potential of biomass as a viable energy resource, however it is but one item on a large menu.

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[6] Ibid., p. 65.

[7] Ibid., P. 65.

[8] Draft Report, Volume II, pp. VIII-117 to -137.

[9] Draft Report, Executive Summary, p. 64.

E. Other Proven Technology Options

Three major "clean" technologies are mentioned as possible options but are assigned relatively modest roles in EPA's proposed stabilizing policy scenarios. These are hydroelectric. and geothermal power. None of these options emit greenhouse gases and all are prominent contributors to the total global electric generation resource base.

Nuclear power currently contributes only about 5% of total global primary energy supplies. In the U.S. 19% of our energy supply comes from nuclear power and our allies in Europe and the East far exceed that. While in Japan over 28% of their power production is nuclear, France has targeted 100% of their power source to be supplied by nuclear power by the year 2000. EPA assumes that its contribution as a climate stabilizing policy would increase to only 8 to 13% by the year 2050. During the same period, biomass would increase its contribution to 21 to 30%.[10] While the current "problems" with nuclear power are well known. we believe that nuclear power can and should play an increased role in meeting mankind's basic energy needs -- with or without the possibility of enhanced global climate change.

A 1984 study by the Office of Technology Assessment (OTA) concludes that "problems that have plagued the present generation of reactors are due to the immaturity of the technology." OTA said that "enough utilities have built nuclear reactors within acceptable cost limits. and operated them safely and reliably to demonstrate that the difficulties with this technology are not insurmountable."[11]

The Draft Report implicitly assumes that lifestyles and values will not change during the timeframe of the scenarios. We suggest a rebuttable presumption exists that mandatory climate stabilizing policies will force -- under threat of adverse climate impacts -- the reevaluation of nuclear and other "hard path" technologies on purely environmental grounds. If the risks of climate change are as great as some claim, then we cannot afford to limit proven technologies such as nuclear power.

The remaining global hydroelectric potential is probably limited, especially in developed countries. However. as the Draft Report suggests. this potential may be significantly undeveloped on a regional basis.[12] We agree. yet the study's "Stabilizing Policy" scenarios exclude aggressive expansion of this resource. Much of the undeveloped hydroelectric potential is in the Third World. These potential resources are also strategically located in terms of their ability to significantly halt deforestation and to mitigate greenhouse gas emissions.[13] The EPA study apparently limits the potential of hydroelectric and geothermal power because "environmental and social impacts ... must be considered carefully."[14] This is disingenuous. If policy options are being evaluated to mitigate global climate change it would seem prudent if not absolutely essential to consider all options. In selecting the most effective options, environmental, social, and economic trade-offs must be recognized. These trade-offs will also be decided on a local basis often by non-Western institutions with non-Western values. EPA's scenarios prejudge the choices of these other nations.

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[10] Ibid.. p. 65.

[11] Office of Technology Assessment. Nuclear Power in an Age of Uncertainty. Summary. Washington. DC: U.S. Government Printing Office. 1984. p.6.

[12] Draft Report. Volume II. pp. VII-155 to -158.

We recommend that before the final draft report EPA should obtain and evaluate dissenting viewpoints on issues related to technology choice and environmental and social trade-offs. Global climate change is too important an issue to warrant limiting the debate to one point of view. We would suggest that greater input also be solicited from other federal agencies and experts from industry.

F. Trade-offs Between Near-Term and Long-Term Options

Enhanced global climate change is a long-term issue. An overcommitment to near-term options may limit or stop development of more effective long-term options.

At issue is how to control the pace of innovation and continue to secure the benefits of future discoveries and inventions. We believe that market forces are the most efficient means of providing that control.

EPA must consider the tremendous advances of the last 50 years as a guide to the minimum level of innovation that can be anticipated in the next 50 years.[15] Future innovations cannot be predicted or forecast.[16] Technologies that will not be available until early in the next century are competing for funds now with more mature or commercialized technologies. We urge that EPA not encourage policies whose implementation could severely inhibit the processes by which new or emerging technologies reach fruition.

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[13] For example: Hydroelectricity in the Himalayas can stop further deforestation of Himalayan rain forests and substitute for fossil-fueled cooking and heating in India, China, and neighboring countries. Nepal alone estimates a hydroelectric potential within its borders of over 83,000 MWs, which is equivalent to total developed hydroelectric capacity in the U.S. Nepal has develop only 161 MWs of hydro capacity to date. (Ministry of Water Resources, Water & Energy Commission Secretariat, "Nepal and Its Water Resources," Katmandu (Nepal), 1988.)

[14] Draft Report, Executive Summary, p. 64.

[15] The technologies that were invented or developed within the last 50 year are unprecedented in history. These technologies are the very foundation of the lifestyles and economies of the developed world and the aspirations of the developing world.

[16] As recently as January 1989, who would have guessed the viability of "cold fusion" as a source of clean energy?

G. Conflicts With Existing Energy Policies

Two prominent policy options advocated by EPA are the phaseout of CFCs (particularly CFC-11 and CFC-12) and mandated appliance efficiency standards. The manufacturers of household refrigerators and freezers are faced with a "Catch-22" situation.

The very substances manufacturers rely upon to produce more energy efficient refrigerators and freezers (CFC-11 and CFC-12) are being gradually phased out by the Montreal Protocol.[17] The EPA "Stabilizing Policy" scenarios assume that the existing agreement is strengthened. At the same time, new regulations are being proposed that mandate increases in energy efficiency for these and other basic home applicances.[18]

The industry relied for almost 50 years on CFC-12 as the basic refrigerant gas and more recently on CFC-11 as a blowing agent for foam insulation. This chemical family was selected based on its qualities as safe, non-toxic and energy efficient.

Appliance manufacturers and CFC producers are committed to phasing out use of these chemicals as soon as is practicable. However, the reality is that there is no known commercially available substitutes for CFC-11 and CFC-12 with comparable energy efficiency capabilities which do not also potentially contribute to the greenhouse effect.

The industry can meet the new proposed standards mandated by the National Appliance Energy Conservation Act. What it cannot do, and what is assumed in EPA's near-term climate stabilizing strategies, is to commit right now to meeting higher standards until it knows what the new CFC substitutes will be. Once it knows this and what their impacts on energy efficiency will be, it can begin to redesign and retool its plant to mass produce the new products.[19] Until such time, the EPA and other policy makers must recognize real-world constraints of certain policy proposals.

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[17] To illustrate the relationship of efficiency increases to use of CFCs, manufacturers increased its use of CFC-11 by 55% to achieve the 96% efficiency increase for refrigerators achieved since 1972 and the 77% increase for freezers.

[18] The National Appliance Energy Conservation Act of 1987 (NAECA) mandates strict new energy efficiency standards for 1990.

[19] In 1988, the members of the Association of Home Appliance Manufacturers produced nearly 8.6 million refrigerators and freezers.

H. Developed Versus Developing Country Perspective on Climate Stabilization Responsibilities

The EPA study clearly documents the fact that U.S. efforts[20] to limit or reduce greenhouse gas emissions have been and will continue to be substantial. Worldwide CO_2 emissions increased from about 1.6 billion tons in 1950 to about 5.1 billion in 1980. The North American share of these emissions decreased from about 45% of the total in 1950 to about 25% in 1980. By the year 2000. North American sources are projected to account for only about 15% of total worldwide CO_2 emissions. These projections recognize rapidly increasing population and energy use in developing countries and increased industrialization in the Soviet Union and Asia.[21]

These examples do not suggest that the U.S. and other industrialized countries walk away from the problem. if enhanced global climate change is proven to be a problem. What it does suggest is that radically different strategies may have to be pursued that are not addressed in the EPA's Draft Report.

For example. mandating new and higher energy efficiency standards in the U.S. may contribute only marginally to climate stabilization relative to more modest standards and controls for developing countries. New mandatory energy efficiency policies in the U.S.. which come on top of significant improvements that have already been made, will be costly.

The easy things have already been done. As the U.S. economy absorbs the costs. the opportunities of developing nations to export their products and raw materials into U.S. markets may decline. thus limiting their ability and commitment to implementing stabilization policies. These economic linkages are clearly critical and further highlight the lack of any meaningful cost analysis in the EPA study.

The results of the recent London conference on stratospheric ozone depletion also illustrate the difficulty in obtaining global consensus to protect the environment when economic self-interest presents a strong countervailing force. That conference considered the strengthening of the Montreal Protocol on limiting the production of chlorofluorocarbons. The EPA Draft Report attempts to consider this issue when it examines changes in predictions of realized global warming if developing countries did not participate. It concluded that failure to obtain developing nation agreement could increase equilibrium warming commitment about 40% in the year 2050, i.e., that substantial risk of global warming exists without full international cooperation.

There are other scenarios that EPA should consider evaluating to assess a broader range of international responses to climate change issues. For example. it would be instructive to consider the impact of the failure of centrally-planned economies to agree to emissions reductions. under an assumption that commitments are obtained from countries with market-based economies. EPA might also consider a scenario limited to adaptation policy options.

V. CONCLUSIONS

The business community appreciates the opportunity to comment on the EPA Report Policy Options for Stabilizing Global Climate Draft Report to Congress. We hope that the EPA takes our concerns into account when finalizing its document.

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[20] In general. this is true for all OECD countries. which include most of the industrialized. market-based economies.

[21] Edison Electric Institute. Testimony of William McCollam. Jr.. Before the United States Senate Energy & Natural Resources Committee on S. 324. the National Energy Policy Act of 1989. March 14. 1989. p. 5.

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